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WRDC-TR-89-8038 (Volume II)

GEOMETRIC MODELING APPLICATIONS INTERFACE PROGRAM (GMAP)

AD-A237 281

UNITED TECHNOLOGIES CORPORATION
Pratt & Whitney
Government Engine Business
West Palm Beach, Florida 33410-9600

September 1989

FINAL REPORT for the Period August 1985 — March 1989
Volume II — Program Description

APPROVED FOR PUBLIC RELEASE
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PREPARED FOR:

MANUFACTURING TECHNOLOGY DIRECTORATE
WRIGHT RESEARCH & DEVELOPMENT CENTER
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This technical report has been reviewed and is approved for publication.

Charles R. Gilman — 9-15-89

Charles Gilman
Project Manager

Date

FOR THE COMMANDER:

Walter H. Reimann — 9-15-89

Walter H. Reimann, Chief
Computer-Integrated Mfg. Branch

Date

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE DISTRIBUTION UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) FR 20802	5. MONITORING ORGANIZATION REPORT NUMBER(S) WRDC-TR-89-8038 Volume II
6a. NAME OF PERFORMING ORGANIZATION United Technologies Corporation Pratt & Whitney Government Products Division 6b. OFFICE SYMBOL (If applicable) (P&W)	7a. NAME OF MONITORING ORGANIZATION Manufacturing Technology Directorate (WRDC/MLTC) Wright Research and Development Center
6c. ADDRESS (City, State and ZIP Code) P.O. Box 9600 West Palm Beach, Florida 33410-9600	7b. ADDRESS (City, State and ZIP Code) Wright-Patterson Air Force Base, OH 45433-6533
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-85-C-5122
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. 78011F0 / PROJECT NO. MTPI / TASK NO. 06 / WORK UNIT NO. 74
11. TITLE (Include Security Classification) GEOMETRIC MODELING APPLICATIONS INTERFACE PROGRAM (GMAP)	
12. PERSONAL AUTHOR(S) L. Phillips, K. Perlotto, D. Koziol Emmerson, P. Blasko, D. Jacobs, R. Disa, J. Wright	
13a. TYPE OF REPORT Final 13b. TIME COVERED FROM 1 Aug 85 TO 31 Mar 89	14. DATE OF REPORT (Yr., Mo., Day) 1989 SEPTEMBER 15. PAGE COUNT 210
16. SUPPLEMENTARY NOTATION Subject to Export Control Law	
17. COSATI CODES FIELD / GROUP / SUB. GR.	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Geometric Modeling Applications Interface Program Product Definition Data Interface Turbine Blades and Disks

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This second Volume of the Final Technical Report summarizes, task-by-task, the technical efforts of the Geometric Modeling Applications Interface Program (GMAP), conducted under U.S. Air Force Contract F33615-85-C-5122. The GMAP Program focused on the computerized generation, control, and exchange of traditional engineering design and manufacturing data. GMAP extended the Product Definition Data Interface Program (PDDI) information model to include computerized support applications for the entire life cycle of a product. GMAP specifically applied product life-cycle support, including engineering, manufacture, inspection, and logistics support, to cooled jet engine turbine blades and disks.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED X SAME AS RPT. ___ DTIC USERS ___	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. Charles Gilman	22b. TELEPHONE NUMBER (Include Area Code) (513) 255-7371 22c. OFFICE SYMBOL WRDC/MLTC

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

FOREWORD

This second volume of the Final Technical Report summarizes, task-by-task, the technical efforts performed under Air Force Contract F33615-85-C-5122, Geometric Modeling Applications Interface Program (GMAP), covering the period 1 August 1985 to 31 March 1989. The contract was sponsored by the Manufacturing Technology Directorate, Wright Research & Development Center, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 45433-6533. This program was administered under the technical direction of Mr. Charles Gilman.

The primary contractor was Pratt & Whitney, an operating unit of United Technologies Corporation (UTC). Pratt & Whitney engaged several additional firms as subcontractors including the United Technologies Research Center (UTRC), McDonnell Aircraft Company (MCAIR), and International TechneGroup Incorporated (ITI) to assist in various tasks of the program. At Pratt & Whitney, the program was managed by Mr. Richard Lopatka. Ms. Linda Phillips was the Program Integrator, and Mr. John Hamill was the Deputy Program Manager.

Note: The number and date in the upper right corner of each page of this document indicate that the volume has been prepared according to the ICAM CM Life Cycle Documentation requirements for a Configuration Item (CI).

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SECTION 1

INTRODUCTION

1.1 PROJECT OBJECTIVES

The Geometric Modeling Applications Interface Program (GMAP) had two primary objectives: (1) identify and organize the geometric and nonshape data needed for the engineering, manufacturing, and logistics support of complex structured components and (2) demonstrate the communication and manipulation of these data for jet engine turbine blades and disks. It was anticipated that attainment of these objectives would improve communication between aerospace prime contractors and their partners, subcontractors, and customers.

The program expanded upon the results obtained in the Product Definition Data Interface (PDDI), Project 5601 (Contract F33615-82-C-5036), which established a mechanism for communicating throughout manufacturing, complete part descriptions as received from engineering. Identifying the classes of information to be included in the PDDI definition constituted a large part of the PDDI project. Establishing a communication format to exchange this part definition constituted the remainder.

The requirement for GMAP stemed from the increasing use of geometric modeler-based software systems in aerospace product life cycle operations and the need to share information produced by these systems in an efficient and cost-effective manner. Geometric modeling is a fundamental building block of the many computer automated design, analysis, manufacturing, inspection, and product support systems that have evolved to date. In the current environment of rapidly evolving computer systems with differing capabilities, there is no single commercial or homegrown software system which can satisfy the needs of all applications. Therefore, the need to integrate systems so that the data they produce and manipulate can be shared is an important requirement that must be developed.

1.2 PROJECT SCOPE

Five technical tasks were employed in GMAP to fulfill its objectives. They are described in the following paragraphs.

Task 1, UNDERSTAND THE PROBLEM, consisted of three subtasks:

1.1 Establish the Management Planning, Project Schedule, and Scope;
1.2 Identify the GMAP Needs;
1.3 Define the System Requirements.

Subtask 1.1 was a comprehensive subtask encompassing the establishment of: an Industry Review Board, Product Assurance/Quality Assurance plans, and coordination with other Computer Integrated Manufacturing projects; selecting a part family for study, and performing a high level functional analysis of the applications involved in the life cycle of the selected part family.

Subtask 1.2 included determining GMAP application interface needs using a "walk-through" of a product's life cycle. Subtask 1.3 established the to-be system requirements from the

SECTION 2

EXECUTIVE SUMMARY

2.1 TASK 1 — UNDERSTAND THE PROBLEM

- The organization; assignment of functions, duties, and responsibilities; management procedures and policies; and reporting procedures were established and documented early in the program. The Pratt & Whitney GMAP Program Office was managed by a Program Manager, a Deputy Program Manager, and a third member, Program Integrator, to unify efforts and to aid in the transfer of technology.

- Pratt & Whitney utilized three subcontractors to assist on various tasks of the original GMAP: McDonnell Aircraft Company (MCAIR), International TechneGroup Inc. (ITI), and United Technologies Research Center (UTRC). Other companies were involved during various GMAP system demonstrations.

- The Program Management Office established Project Master Schedules that both Pratt & Whitney and program subcontractors agreed to follow.

- After Task responsibilities were assigned, the GMAP participants used the IDEF0 function modeling methodology to describe Pratt & Whitney's design and manufacturing facilities for jet engine turbine blades.

- An upper level GMAP scoping function model was created to help provide an understanding of the role GMAP will have in the product life cycle of turbine blades, disks and assemblies.

- A family of jet engine turbine blades and disks was selected for the detailed walkthroughs of the life cycle activities associated with the design, manufacture, and support of these parts.

- Candidate functional applications for demonstration of GMAP technology were identified after applying IDEF0 modeling techniques during the detailed functional modeling walkthroughs.

- Three walkthrough teams were set up, combining the related functions of Design with Analysis; Manufacturing with Inspection; and Product Support with Logistics Support.

- Approximately 100 functional applications were identified with the IDEF0 function model, many of which were supported by computer programs, including: graphic systems, geometry processors, N/C toolpath utilities, cooling hole laser drilling programs, coordinate measuring machine program generators, finite element stress programs, and tolerance chart programs.

identified needs, and completed a State-of-the-Art Survey of existing capabilities that identified both the minimum, and the functional, requirements of a product modeler.

Task 2, ESTABLISH THE PRELIMINARY AND DETAILED DESIGN, consisted of four subtasks:

2.1 Establish Preliminary Design,
2.2 Review Preliminary Design,
2.3 Establish Detail Design,
2.4 Perform Critical Design Review.

In Subtask 2.1, a conceptual design for GMAP was developed, including identification of required enhancements to PDDI technology and a plan for testing the GMAP system software. In subtask 2.2, this work was reviewed to ensure that the design met all of the system requirements established in Task 1. Subtask 2.3 detailed the design, and established plans for testing logistic application interfaces. Subtask 2.4 ensured review of the detail design.

Task 3, INTEGRATE EXISTING FUNCTIONAL APPLICATIONS, consisted of designing interfaces for two existing functional applications, the Retirement for Cause disk inspection system and the Integrated Blade Inspection System, at the Air Force's San Antonio-Air Logistics Center.

In Task 4, BUILD AND INTEGRATE THE APPLICATION INTERFACE, GMAP software was constructed and the function, performance, and integration of the system was verified in accordance with the design and test plans established in Tasks 2 and 3. Applicable manuals were produced for the installation and operation of the system.

Task 5, IMPLEMENT, MAINTAIN, AND DEMONSTRATE GMAP, included four Subtasks:

5.1 Implement GMAP,
5.2 Maintain GMAP,
5.3 Project Performance and Benefits Analysis,
5.4 Demonstrate GMAP.

Subtask 5.1 demonstrated the effectiveness of the GMAP system by implementing it on contractor, customer and outside supplier computer systems. Subtask 5.2 provided modifications to the GMAP system during testing as required. Subtask 5.3 identified the potential benefits if GMAP was fully implemented on life cycle applications. Under Subtask 5.4, several videotapes were produced to demonstrate the GMAP system performance.

In addition, Task 6, DELIVERABLE REPORTS, was included as part of GMAP to account for documentation. A variety of technical and financial reports were produced in accordance with the Contract Data Requirements List (DD Form 1423) and the Integrated Computer Aided Manufacturing Life Cycle Documentation Schedule. The majority of these documents are discussed in connection with the technical efforts that they support.

- The design and analysis walkthrough took place at the Pratt & Whitney facilities in West Palm Beach, Florida. It involved a total of 17 interviews with 29 experts from various discipline areas.

  In design and analysis, the amount of computerization and electronic interface ranged from complete to partial. This area created the Product Definition Data (PDD) that is carried in both electronic and paper forms. The walkthrough also showed that several specific design and analysis disciplines worked together to produce a final part design.

- Identification of manufacturing and inspection candidate functional applications also occurred with the IDEF0 analysis described previously. The manufacturing and inspection walkthroughs were conducted at five different facilities throughout Connecticut and in Georgia.

  Manufacturing was broken into six major functions that were investigated to identify and track the use of PDD. Manufacturing functions were decentralized and highly dispersed. This pointed out a benefit to using electronic PDD. Suppliers were highly involved in the manufacturing process. Production planning was the key function in the development and use of PDD. All other functions relied on production planning as their primary source of technical information and analysis.

- Product Support consisted of all support activities necessary to service customers that purchased Pratt & Whitney engines. It provided technical information and instructions, processed warranty claims, provided pricing information, processed orders for spare parts, established logistic requirements, and forecast future parts needs.

- Two specific areas within logistics support dealing with inspection processes were studied. One dealt with blades, the Integrated Blade Inspection System (IBIS); the other with disks, Retirement for Cause (RFC). Logistics support involved the disassembly, inspection, service, repair, and reassembly of in-service aerospace products.

  IBIS provided an automated blade inspection capability for the logistics support facility. Three inspection submodules performed the actual inspection: the Fluorescent Penetrant Inspection Module, the Infrared Inspection Module, and the X-Ray Inspection Module.

  The RFC system was an automated, robotics-based inspection system developed by Systems Research Laboratories, Inc in Dayton, Ohio, for the San Antonio Air Logistics Center (SA-ALC). It was used to detect engine disk surface and internal flaws using eddy current and ultrasonic nondestructive evaluation techniques.

- Pratt & Whitney investigated other Air Force Materials Lab CIM Branch programs as well as industry efforts to establish technology transfer opportunities.

- An Industry Review Board (IRB) was established to review the progress of GMAP; assess the technical direction of the project; offer advice from a broad base of industrial background and experience; and provide an important vehicle to assist with the transfer of GMAP technology to industry in general. Mr. G. Hess, Vice President — Systems and Planning for Ingersoll Milling Machine Company, agreed to be the Chairman of the IRB. Mr. J. Lemon, President of International TechneGroup, Inc., agreed to be Secretary of the IRB.

  There were six IRB meetings. Each meeting reviewed the technical progress of the program and provided a forum for technical guidance.

- Pratt & Whitney prepared a Software Quality Assurance Plan to ensure that computer software developed during the program conforms to quality requirements in a cost-effective manner. The Plan applied to all program software deliverable to the Air Force.

2.2 TASK 2 — ESTABLISH THE PRELIMINARY AND DETAILED DESIGN

- Approximately 100 candidate functional applications were identified for IDEF1X methodology information modeling. Sixteen key functional application areas were selected from the 100 for evaluation of information, or data, needs.

- The PDD needs for each of the 16 applications were converted into specific types of data that would be needed across a broad spectrum of industry. This resulted in seven classes of data: Geometry, Topology, Form Features, Shape, Tolerances, Nonshape and Notes, and Administrative and Assembly.

  Key findings relating to these needs were:

  For complex mechanical components, PDD must include all concepts, attributes, and relationships normally communicated from design throughout the product life cycle. The engineering drawing and related technical documents have been the vehicles historically used for this purpose. For complex mechanical components, both shape and nonshape information and process requirements are needed to represent fully a component or assembly.

  Applications that are users of PDD, as opposed to those that are producers of PDD, are the primary beneficiaries of an electronic equivalent of the engineering drawing.

  Computer-sensible product data are needed for applications to become more automated. This is especially true for most applications studied in manufacturing, inspection, and logistics support.

The primary responsibility for creating PDD lies within the traditional mechanical design and drafting functions.

Modelers need to be developed to create the required PDD. These modelers may actually be a system of modelers capable of providing the various shape and nonshape data required. For shape data, existing geometric and solid modelers are capable of producing the geometry and topology definitions required by some using applications, but not without problems and limitations.

"In-process geometry" must be derivable and representable from PDD for Process Planning, N/C Machining, Automated Inspection, and Tool Design Applications.

There is a need to preserve the constructive origins of shape PDD for some applications.

Although solid model representation of shape is required for certain automated applications, not all applications require such complete information. Some applications only require 2-D geometry. Examples are applications dealing with Body of Revolution (BOR) or turned parts, and flat sheet-like parts.

There is a need to represent geometry in multiple forms depending upon the using application. This leads to the requirement for standardized representations. Evaluator utilities capable of converting between standard forms would be very useful.

Features are a key to applications such as automated process planning, since features are the result of individual processes.

Tolerances, datums, and their relationships to part shape are fundamental to future automated applications. Representations of tolerances and datums must parallel traditional industry standards for reasons of acceptability, useability, traditional practice, and so on.

Process requirements normally conveyed to manufacturing and inspection via notes and specification invocation on engineering drawings must continue to be conveyed in the electronic PDD form. The bulk of this information needs to be represented in a computer-sensible form. Other information is only human understandable and needs to be conveyed via note text in the PDD model.

Information is communicated from engineering and product support to logistics support by using the technicac order. This

information is analogous in form to the process requirements communicated from engineering to manufacturing. Provisions for incorporating these data in the full PDD model are essential.

Administrative information pertaining to the control and management of the PDD needs to be included with the technical PDD.

Assembly PDD is normally conveyed using layout and assembly drawings. Information contained on these traditional documents falls into categories similar to those required for component PDD. These are geometry, topology, features, tolerances, non-shape and notes (process requirements being assembly requirements in this case), and administrative.

- PDD requirements of the GMAP system were synthesized from the results of the needs analysis and presented in the form of entities.

- The minimum requirements of a product modeler were established. Such a modeler is required to take advantage of the complete PDD capabilities provided by GMAP.

- Pratt & Whitney contracted D. Appleton Company (DACOM) to produce a follow-on document entitled "Functional Requirements of a Product Modeler."

- A survey was conducted to identify current and emerging technologies that impact the content, usage, exchange, and management of PDD models. This survey also identified technology voids by correlating the prioritized needs from the GMAP Needs Analysis Document with the survey findings. It was found that completely integrated product modelers were not yet available.

- To establish a preliminary design, IDEF1X information modeling was performed for each data class. In the process, a new data class, the "Shape" data class was added to the GMAP schema. The concepts provided by the Shape data class helped accelerate the work of the PDES community.

- The System Test Plan provided a strategy for testing and validating the elements and functionality of GMAP as defined in the System Design Specification.

- Enhancements or additions to the PDDI software were identified in four areas: PDD model access, Schema Manager, PDD Editor, and System Translator performance improvements.

  The Name/Value Interface (N/VI) enhancement to PDD model access freed application programs from the need to be concerned with the physical location of attribute values within an entity in the working form of the product model.

The Schema Manager was necessary to create entity definitions. The Schema Manager would improve the flexibility of the software for both growth and development.

The PDD Editor was designed to populate PDD models with entities as defined in the schema. It could also create, modify, delete, and view the PDD contained in the working form model.

The System Translator is a software mechanism developed under PDDI for passing data between dissimilar systems. Enhancements were also implemented to make the System Translator conform to the PDES exchange format. Several enhancements were made that reduced the CPU time for System Translator operation.

- Review of the progress and the technical adequacy of the GMAP system design was conducted as part of the the third IRB meeting during April 1987.

- The GMAP System Component As-designed Product Specification (CI FTR560240031U) established the design of the GMAP System Components.

- Because of the close coordination with the Air Force and the IRB in establishing the detail design, no formal critical design review was performed.

2.3 TASK 3 — INTEGRATE EXISTING FUNCTIONAL APPLICATIONS

- The GMAP-to-RFC Interface was designed (1) to translate the GMAP disk model PDD from exchange format to working form in VAX computer memory and (2) to translate the model in working form to the Unigraphics data base that is resident on the RFC system at System Research Laboratories.

- The GMAP-to-IBIS Interface was designed to (1) derive an IBIS-compatible, bi-cubic patch surface representation of the blade from the Non-Uniform Rational B-spline (NURB) surface representation contained in the GMAP model and (2) extract the flaw criteria and inspection zone information from the GMAP model and make them available to the Inspection Plan Generation Subsystem of IBIS.

- RFC and IBIS Unit Test Plans were developed to assure that each requirement stated in the respective Development Specification would be adequately validated, and that the data generated during demonstrations would verify that the performance objectives were met.

2.4 TASK 4 — BUILD AND INTEGRATE APPLICATIONS INTERFACE

- The software that comprises the GMAP system and which was delivered to the Air Force includes eight components.

System Translator — A software mechanism used for passing data between dissimilar systems initially developed under PDDI and enhanced in GMAP.

The Model Access Software with N/VI — The Model Access Software is a set of routines that allow access to product models for creation, modification, deletion, and navigation at the entity level. The N/VI is a set of PASCAL subroutines that help query the PDD model about entity attributes. It helps avoid altering an application program when certain elements of that program's PDD model are changed by freeing the application programs from the need to know the physical location of an attribute for an entity. It provides access at the attribute level.

Schema Manager — One of two new components developed in GMAP, it creates the Data Dictionary and PASCAL include files and manages the schema. The Data Dictionary and PASCAL include files are the physical files that define the data schema to the system components and applications.

PDD Editor — The second of two new components developed in GMAP, it adds PDD such as tolerances, form features, administrative and assembly data, etc. to demonstration models for each application from Data Dictionary definitions.

Data Dictionary — A listing of all the possible entity definitions that could occur in any model including their names, data types, size, displacement and usage. It is used primarily in FORTRAN programs.

PASCAL Include Files — Representations of the Data Dictionary for use in PASCAL application programs.

Interfaces to the Air Force's RFC and IBIS at the San Antonio Air Logistics Center.

- Commercial modeling systems in use at Pratt & Whitney were used for the initial geometry and topology creation of the GMAP PDD models for testing. These systems included the Computer Aided Engineering Design System (CAEDS), Computervision's CADDS4X system, and Manufacturing Consultant Services' ANVIL 4000 system. Additional PDD, such as tolerances, nonshape, form features, and so on were added by the PDD Editor where required.

- Testing was conducted on the individual GMAP system components as well as on the integrated GMAP system through application demonstrations.

  The Parametric Cooled Turbine Blade demonstration focused on an F100 1st stage turbine blade. An improved design method for this blade was demonstrated by directly translating design data, parametrically generating and modifying geometry, and finally, by preparing a complete part model through use of the PDD Editor. The resulting PDD model, which contained geometric

and nonshape data, was a source for subsequent GMAP blade life cycle application demonstrations.

The Casting Tooling application dealt with the manufacture and inspection of an EDM Electrode used to machine the core in a mold as part of the turbine blade casting process. The entire casting tooling application consisted of four applications:

Supplier N/C Machining. Mold Masters Inc., a Pratt & Whitney casting tooling supplier used a GMAP model to machine the electrode, demonstrating supplier base integration.

Internal N/C Machining. An internal Pratt & Whitney group used the same GMAP model to machine an electrode.

CMM Inspection. The upper surface of each electrode was inspected using GMAP product data.

Automated Optical Inspection. The electrode ribs and trip strips were inspected by Optical Gaging Products Inc. using GMAP product data.

The GMAP-to-IBIS Interface read an exchange format file of a turbine engine compressor blade and produced output files that were to be used in the IBIS system for generating scan plans that drive blade inspection operations.

The disk design application used the F100 turbine disk. A computerized disk file was read into a SUN-based Computervision CADDS4X system where a solid model was generated to calculate mass properties such as center of gravity, weights, moments of inertia, volumes, and so on. A shaded picture was also created to assist in surface visualization. Based on this output, the model was either accepted as a final design, or modified and reprocessed through the above steps.

The PROCAP program fed process capabilities back to engineering and process planning. PDD from the GMAP model were specified as parameters in a search for similar part types, materials, and features. Each manufacturing operation and process capability found to match the search parameters were displayed to aid the designer in the tolerancing of the disk features.

The Feature-Based N/C Machining and CMM Inspection Programming application used form features, such as scallops and bolt hole pattern, and related product information such as topology, geometry, tolerances, and nonshape data from the disk PDD model. This information was used to automate the generation of both N/C and CMM source programs.

The Disk Forging application focused on supplier base integration between Pratt & Whitney and a major supplier of disk forgings. A Supplier's Report of Nonconformance (SRON), typically used by suppliers to report nonconformances was used to demonstrate the feedback of process data closely related to the product definition from a downstream life cycle function within a supplier's facility to the contractor.

The RFC Interface read an exchange format file that described a turbine engine disk and technical order data, and produced Unigraphics parts that were to be used in the RFC system for generating scan plans that drive disk inspection operations.

The Engine Case Boss Inspection application was jointly conducted by Pratt & Whitney and the Department of Mechanical Engineering at RPI, in Troy, New York. This application showed GMAP could support more typical industrial parts than turbine blades and disks.

The Case Boss N/C Programming application was jointly conducted by Pratt & Whitney, Automation Technology Products, and Ingersoll Milling Machine Company. It demonstrated the use of GMAP components to build and transfer a product model of a plumbing attachment boss.

The PDDI Program demonstrations Display Query and Classification and Coding were redemonstrated to verify that the Model Access Software and System Translator, enhanced for GMAP, operated in conjunction with the original demonstration software and models.

- The System Components Operator's Manual (CI OM560240001U), the Schema Manager User's Manual (CI UM560240011U), the System Translator User's Manual (CI UM560240021U), the Model Access Software User Manual (CI 560240031U), and the PDD Editor User's Manual (CI 560240041U) were prepared to document the installation and use of the GMAP software.

2.5 TASK 5 — IMPLEMENT, MAINTAIN, AND DEMONSTRATE GMAP

- The GMAP system software was installed at McDonnell Douglas facilities to test the components as part of the development process. Additional implementations of GMAP occurred as part of the application demonstrations.

- Very little system maintenance was required to keep the GMAP system operational throughout the demonstration period.

- The successes of the applications demonstrated across the product life cycle offered several benefits from implementing GMAP in a environment similar to that in which the demonstrations were performed.

- GMAP technology was demonstrated at the end of the program in five videotapes:

    1. Executive Overview
    2. Technical Summary
    3. Blade Life Cycle
    4. Disk Life Cycle
    5. Plumbing Attachment Boss Demonstrations.

2.6 TASK 6 — DELIVERABLE REPORTS

- A variety of technical and financial reports were produced in accordance with the Contract Data Requirements List (DD Form 1423) and the Integrated Computer Aided Manufacturing Life Cycle Documentation Schedule. These reports are documented in Section 4. A request form is included.

SECTION 3

PROJECT ACCOMPLISHMENTS

Section 3 describes the accomplishments of the GMAP effort in serial order by Task and Subtask.

3.1 TASK 1 — UNDERSTAND THE PROBLEM

Task 1 consisted of three subtasks:

1.1 Establish the Management Planning, Project Schedule, and Scope
1.2 Identify the GMAP Needs
1.3 Define the System Requirements.

Subtask 1.1 was a comprehensive subtask encompassing the establishment of: an Industry Review Board, Product Assurance/Quality Assurance plans, and coordination with other Computer Integrated Manufacturing projects; selecting a part family for study, and performing a high level functional analysis of the applications involved in the life cycle of the selected part family.

Subtask 1.2 included determining GMAP application interface needs using a "walkthrough" of a product's life cycle. Subtask 1.3 established the to-be system requirements from the identified needs, and completed a State-of-the-Art Survey of existing capabilities, identifying both the minimum, and the functional, requirements of a product modeler.

3.1.1 Establish the Management Planning, Project Schedule, and Scope (Subtask 1.1)

3.1.1.1 Management Planning

The organization; assignment of functions, duties, and responsibilities; management procedures and policies; and reporting procedures were established and documented early in the program. Although minor changes were made as the program progressed to accommodate changes in personnel, the overall management structure and methods for monitoring, reviewing, and controlling remained the same. These components to the GMAP management plan are described below.

3.1.1.1.1 Pratt & Whitney Program Office

The Pratt & Whitney GMAP Program Office was managed by a triad. A third member, Program Integrator, was added to the typical management team to unify efforts and to aid in the transfer of technology. The following paragraphs indicate the major areas of Program Office responsibilities.

Program Manager

Pratt & Whitney's Program Manager, Mr. R. Lopatka, was responsible for providing program visibility to top management. In addition, he provided:

- Long-term program direction
- Monitoring of overall program progress
- Primary management for technical control, resource control, customer interface, and contract cost and schedule performance.

Program Integrator

The Program Integrator, Ms. L. Phillips, was the designated point of contact with the government to ensure prompt customer response. Other position responsibilities included:

- Coordinating technical activities of the GMAP subcontractor efforts
- Controlling technical developments to assure early identification of problem areas and prompt resolution
- Being the liaison for technology transfer activities among industrial, academic, and Government programs.

Deputy Program Manager

The Deputy Program Manager, Mr. J. Hamill, was responsible for:

- Monitoring implementation of contracts with GMAP partners
- Financial administrative tasks, (i. e., cost collection, cost analysis, documentation, etc.)
- Industry Review Board meeting management.

3.1.1.1.2 Pratt & Whitney/Air Force Interface

Interaction between the GMAP team and the Air Force was via periodic formal program reviews that provided oral and written data in compliance with the Contract Data Requirements List (CDRL). Informal communication was also provided to the Air Force Program Office as events in the program warranted. The Program Integrator was the principal contact with the Air Force on technical issues.

3.1.1.1.3 Subcontractors

Pratt & Whitney utilized three subcontractors to assist on various tasks of the original GMAP: McDonnell Aircraft Company (MCAIR), International TechneGroup Inc. (ITI), and United Technologies Research Center (UTRC). Each subcontractor had a program office that

interfaced with Pratt & Whitney's Program Integrator. This procedure unified project activities and controlled changes as needed.

The Work Breakdown Structure (WBS) for GMAP was expanded and an activity network was defined. Each element of the activity network was a work package that was the responsibility of a the prime contractor or a subcontractor. Table 3-1 depicts the contractual responsibilities of each of these subcontractors by Task and Subtask.

Other companies were involved during various GMAP system demonstrations. Each such company established a Program Office and identified the primary focal point for interaction with the Pratt & Whitney GMAP Program Office.

3.1.1.2 Project Schedule

In an iterative process that took into account the task breakdown and responsibility assignments presented in Table 3-1, the Program Management Office established Project Master Schedules that both Pratt & Whitney and program subcontractors agreed to follow.

These schedules, depicted in Figures 3-1 through 3-5, show the period of performance for the overall program as well as for each of the technical tasks.

3.1.1.3 Scope

After Task responsibilities were assigned, the GMAP participants used the IDEF0 function modeling methodology, referencing the Design0 and Manufacturing0 models, to describe Pratt & Whitney's design and manufacturing facilities for jet engine turbine blades and disks.

A sample part family of jet engine turbine blades and their corresponding disks was then identified. Next, candidate applications with which to demonstrate the GMAP system were identified. Coordination was established with other CIM projects including PDDI, the National Bureau of Standards' (now National Institute of Standards & Technology [NIST]) Initial Graphics Exchange Specification/Product Data Exchange Standard (IGES/PDES) project, and Computer Aided Manufacturing-International (CAM-I) projects dealing with geometric modelers and applications interfaces. The paragraphs below describe the scoping effort in more detail.

3.1.1.3.1 Design0 and Manufacturing0

An upper level GMAP scoping function model was created to help provide an understanding of the role GMAP will have in the product life cycle of turbine blades, disks and assemblies. The Air Force's view of a generic aerospace facility is documented in ICAM Design0 (AFWAL-TR-81-4023, vol. vii) and Manufacturing0 (AFWAL-TR-81-4023, vol. viii) documents.

TABLE 3-1.

TASK BREAKDOWN OF SUBCONTRACTOR RESPONSIBILITIES

Subtask: 1.1

Establish Management Planning, Project Schedule, & Scope

Activity	P&W	MCAIR	ITI	UTRC
Plan/Schedule	Create PMP/PMS	Provide input	Provide input	Provide input
Scope	Create SD	Provide input	Provide input	Provide input
Design0/1 Mfr0/1	Direct UTRC Review	--	--	Gather info create charts
Sample part family	Create matrix	--	--	--
Identify Functional applications	Look into P&W System	Look into RFC	Look into IBIS	Conduct interviews create IDEFØ
Coordinate with other CIM activities	Establish plan	PDDI interface	Support as required	--
IRB	Establish IRB	Support as required	Coordinate IRB activities	Support as required
PA/QA	Establish plan to be used for GMAP	Provide PA/QA plan for work on GMAP	Provide PA/QA plan for work on GMAP	Provide input

TABLE 3-1.

(CONTINUED)

Subtask: 1.2

Identify GMAP Needs

Activity	P&W	MCAIR	ITI	UTRC
Establish INFO	IDEF1 PO for P&W Life Cycle	IDEF1 PO for RFC	IDEF1 PO for IBIS	Support as required
	IDEF1X PO - Create Service Material Log and Source Data List IDEF1X P1 - Develop Entity Classes IDEF1X P2 - Develop Relation Classes IDEF1X P3 - Develop Key Attribute Classes IDEF1X P4 - Develop Nonkey Attribute Classes Produce the final IDEF1 model			
Derive and analyze GMAP needs	Produce preliminary needs list	Provide input	Provide input	--
	Associate benefits to needs Collect, review & integrate work Prioritize needs Establish specific needs to be supported by GMAP			
Review NAD	Create the NAD	Provide input for RFC Review	Provide input for IBIS Review	Review

TABLE 3-1.

(CONTINUED)

Subtask: 1.3

Define the System Requirements

Activity	P&W	MCAIR	ITI	UTRC
Establish the GMAP requirements	The Principal Investigator will review IDEF1 model and identify entity/attribute/ relation classes needed to support GMAP. Compare GMAP and PDDI IDEF1 models to determine PDDI changes and extensions.			
Establish minimum requirements	Direct & monitor ITI	Review	Establish the minimum requirements*	Review
Perform the State-of-the-Art survey	Monitor activities	Review	Collect information Evaluate findings Create report	Provide input as required Review
Review Requirements Definition	Produce SRD linking to RAD	Provide support Review	Review	Review

*D. Appleton Company produced follow-on document entitled "Functional Requirements of a Product Modeler".

TABLE 3-1.

Subtask: 2.1 (CONTINUED)

Preliminary Design

Activity	P&W	MCAIR	ITI	UTRC
Conceptual Design	Define alternative designs for the applications interface using PDDI and results of the SRD	Support as required	Support as required	Possible IDEF2
Review Conceptual Design	Create Draft to Conceptual Design	Review	Review	Review
Produce Preliminary Design	Create SDS, DS, STP	Provide input regarding PDDI	Support as required	Provide input as required
Produce SDS	Create SDS	Design PDDI enhancements	Support as required	Provide input as required
Identify Enhancements to total PDDI System Arch.	Direct & Monitor MCAIR	Identify enhancements	Support as required	Provide input as required
Identify Enhancements to PDDI EF	Direct & Monitor MCAIR	Identify enhancements	Support as required	Provide input as required
Identify Enhancements to PDDI Access Software and working form	Direct & Monitor MCAIR	Identify enhancements	Support as required	Provide input as required
Identify links to corporate Info Systems	Identify links at P&W	Provide input relating to RFC	Provide input relating to IBIS	IDEF model support
Produce DS	Direct & Monitor MCAIR and ITI	Create RFC DS	Create IBIS DS	—
Establish System Test Plan	Create the System Test Plan	Provide input	Provide input	

TABLE 3-1.

(CONTINUED)

Subtask: 2.2

Review Preliminary Design

Activity	P&W	MCAIR	ITI	UTRC
Review Preliminary Design	Present Documents at Review	Present Documents at Review	Present Documents at Review	Assistance as required

Subtask: 2.3

Establish Detail Design

Activity	P&W	MCAIR	ITI
Establish Product Specification	Direct & Monitor MCAIR and ITI	Create RFC PS	Create IBIS PS
Establish Unit Test Plan	Direct & Monitor MCAIR and ITI	Create RFC UTP	Create IBIS UTP

Subtask: 2.4

Perform Critical Design Review

Activity	P&W	MCAIR	ITI
Perform Critical	Present material	Participation as Required	

TABLE 3-1.

(CONTINUED)

Subtask: 3.1

Establish Interface to RFC

Activity	P&W	MCAIR	ITI
Produce RFC Preliminary Design	Direct & Monitor MCAIR	Produce the Preliminary Design input for 4.2.1.3	—
Review RFC Preliminary Design	Support MCAIR at Review	Present Documents at Preliminary Design Review	—
Produce RFC Detail Design	Direct & Monitor MCAIR	Expand the Preliminary Design for the RFC input	—
Review RFC Detail Preliminary Design	Support MCAIR at the CDR	Present Detail Design for RFC at the CDR (4.2.4)	—

Subtask: 3.2 Establish Interface to IBIS

Activity	P&W	MCAIR	ITI
Produce IBIS Preliminary Design	Direct & Monitor ITI activities	—	Produce the Preliminary Design
Review IBIS Preliminary Design	Support ITI at Review	—	Present Documents at Preliminary Design Review
Produce IBIS Detail Design	Direct & Monitor ITI	—	Expand the Preliminary Design for the IBIS
Review IBIS Detail Design	Support ITI at the CDR	—	Present Detail Design for IBIS at the CDR (4.2.4)

TABLE 3-1.

(CONTINUED)

Subtask: 4.1

Construct and Verify the Application Interface

Activity	P&W	MCAIR	ITI
Construct the GMAP	Direct & Monitor MCAIR & ITI Implement the GMAP application interfaces per the design	Implement the PDDI enhancements Implement the RFC design	Implement the IBIS Design
Test the Software	Direct & Monitor testing in accordance with the Unit Test Plan Produce the Unit Test Report	Conduct Unit Test of PDDI enhancements and RFC Provide test results	Conduct Unit Test of IBIS Provide test results

TABLE 3-1.

(CONTINUED)

Subtask: 4.2

Integrate and Validate the System

Activity	P&W	MCAIR	ITI
Construct the system	Ensure system manuals are created. Provide documents for the GMAP.	Enhance the system manuals of PDDI to include GMAP, UM, OM, MM. Produce the application manuals for RFC Interface; UM, OM, and MM.	Produce the application manuals for IBIS Interface; UM, OM, and MM.
Test the System	Conduct the system test for the selected application interfaces. Document the test results.	Conduct the PDDI tests. Conduct the RFC test. Provide test results.	Conduct the IBIS test. Provide test results.

TABLE 3-1.

(CONTINUED)

Subtask: 5.1, 5.2, and 5.3

Implement and Maintain GMAP

Activity	P&W	MCAIR	ITI	UTRC
Implement GMAP	Produce an implementation plan. Load software for Demo at P&W and at selected suppliers	Provide input Load software at SRL for RFC demo and at MCAIR for PDDI test	Provide input Load software at SA-ALC for IBIS demo	--
Maintain GMAP	Maintain software loaded to perform GMAP Demos	Maintain software loaded to perform PDDI and RFC Demos	Maintain software loaded to perform IBIS Demo	--
Project Performance and Benefits Analysis	Document findings in a cost model describing the impact of GMAP	Write plans and conduct Benefit Analysis for GMAP to RFC Interface	Assist P&W	Assist P&W

TABLE 3-1.

(CONTINUED)

Subtask: 5.4

Demonstrate GMAP

Activity	P&W	MCAIR	ITI
Demonstrate the exchange format	Demo on P&W systems	Assistance as required	--
Demonstrate the Access Software	Demo on P&W systems	Assistance as required	--
Demonstrate the Supplier Base Integration	Demo involving P&W Supplier(s)	Assistance as required	--
Demonstrate the GMAP using the PDDI Part Classes	Direct & Monitor MCAIR	Demo on MCAIR systems	--
Demonstrate the GMAP-IBIS Interface	Direct & Monitor ITI	Assistance as required	Demo on SA-ALC IBIS system
Demonstrate the GMAP-RFC Interface	Direct & Monitor MCAIR	Demo on SA-ALC RFC system	--

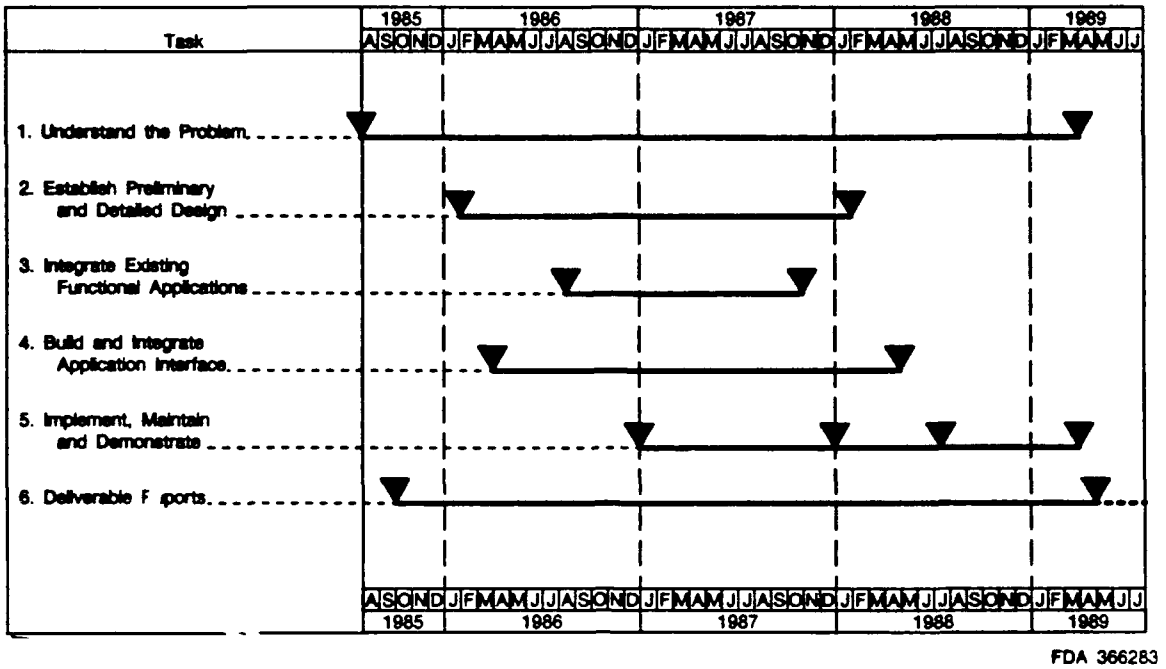

Figure 3-1. Overall Program Schedule

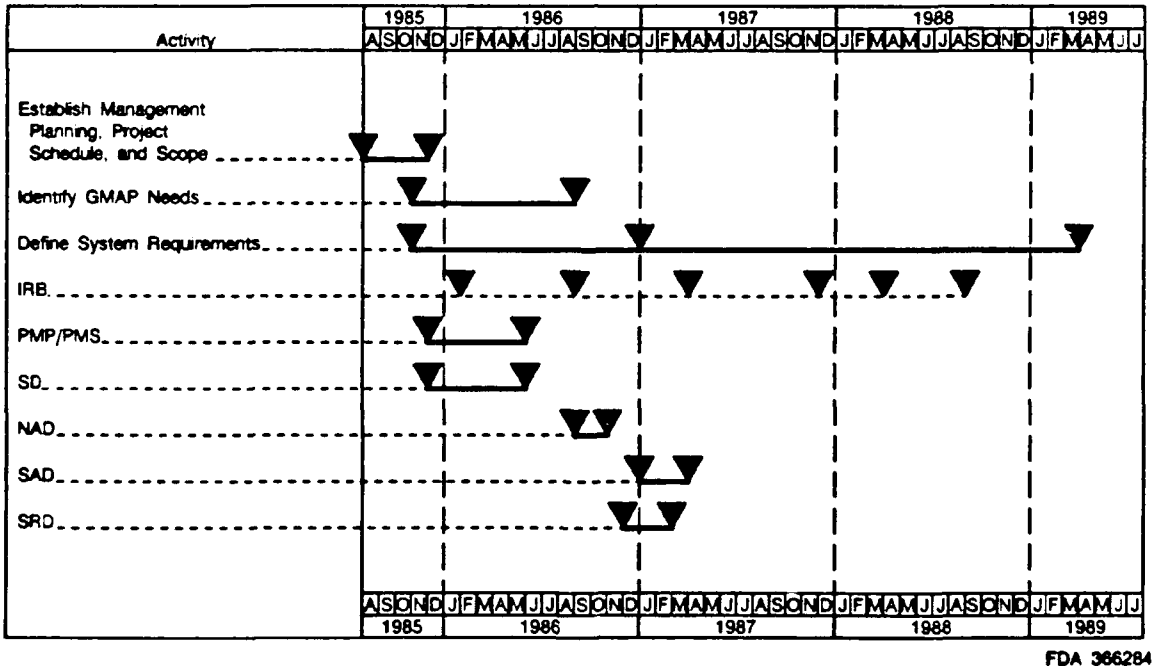

Figure 3-2. Task 1 — Understand the Problem

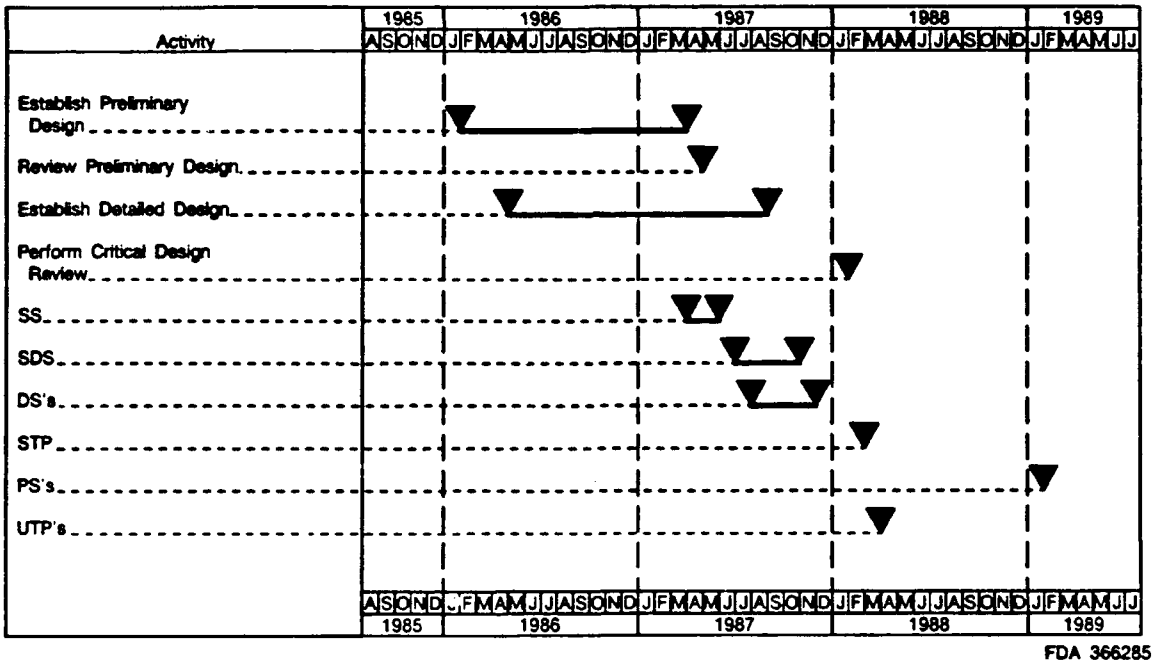

Figure 3-3. Task 2 — Establish Preliminary and Detail Design

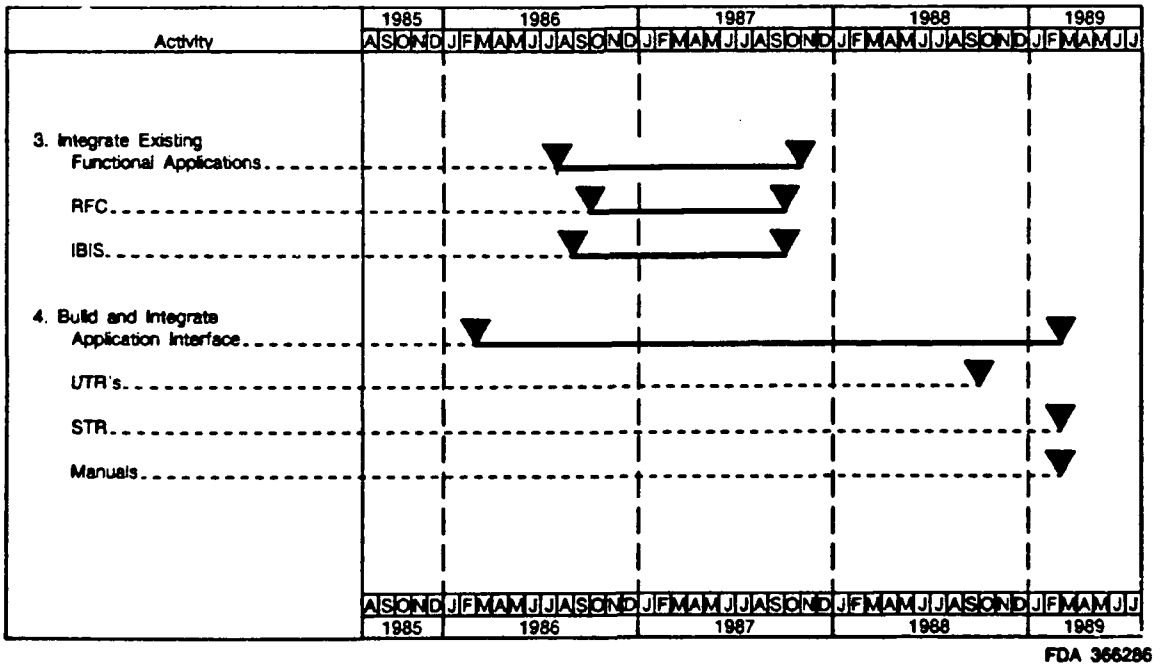

Figure 3-4. Tasks 3 and 4 — Integrate Existing Functional Applications and Build and Integrate the Application Interface

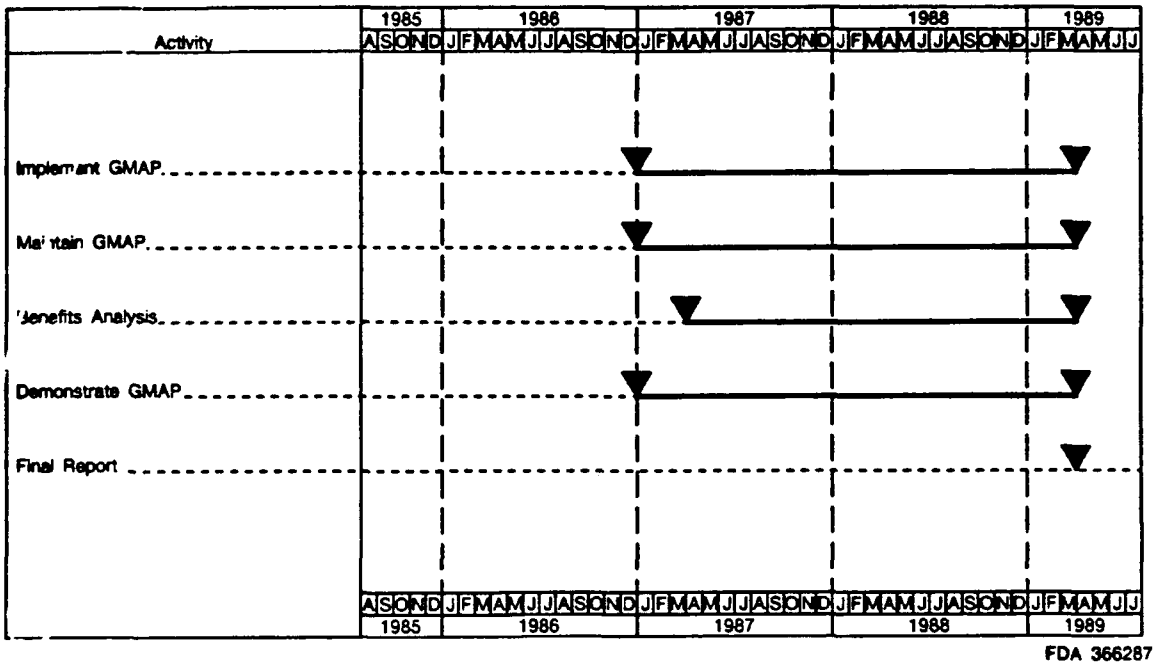

Figure 3-5. Task 5 — Implement, Maintain, and Demonstrate GMAP

These models were used as a basis for development of the GMAP upper level function model. The upper level GMAP function model was examined to identify key functions that were analyzed in greater depth during the detailed activity modeling. GMAP focal points were identified from the upper level functional model. Certain activities identified were later determined to not have an impact on GMAP. The model was developed from information gathered during interviews with Pratt & Whitney personnel representing Engineering Design and Analysis, Manufacturing and Inspection, Quality Assurance, and Product Support. The information gathered was also used to establish a logical progression into the next step of detailed function modeling, which concentrated on activities specific to turbine blades, disks and assemblies.

Pratt & Whitney operational unit managers, with broad experience and knowledge in the day-to-day operations of the overall product life cycle were interviewed by a team consisting of IDEF0 modelers from UTRC, a Principal Investigator from Pratt & Whitney, and supporting technical staff, as required. The Principal Investigators were responsible for arranging the interviews and directing the area of pursuit. The modelers recorded and transcribed the gathered data into IDEF0 models. This process was termed a modeling walkthrough.

The model captured the upper level perspective of the relationships of the life cycle activities within the turbine blade and disk part families. These models, exhibited in Appendix A, consist of three levels, beginning with GMAP/A-0 "Develop and Produce Engine Products". The resources and products of the various activities are illustrated as well as the mechanisms employed by the activities and their controlling factors. These models were a formal guide to the further detailed activity modeling phase.

A hierarchical node tree diagram is also exhibited in Appendix A. This node tree illustrates the relationships of the activities from the upper level viewpoint. It graphically illustrates, through the use of shaded nodes, the scope of GMAP with respect to these upper level functions.

Product data in the form of graphic and text descriptions impact each of the six functions within the GMAP/A3 function (Produce Engine Product) to varying degrees. Results of the high level (scoping) walkthroughs indicate that A33 (Plan Production) was the key technical function that used PDD within manufacturing. Therefore, it was decided that the detailed walkthroughs would concentrate on this function. Other functions would be evaluated to varying degrees.

3.1.1.3.2 Select Sample Part Family

A family of jet engine turbine blades and disks was selected for the detailed walkthroughs. By investigating the life cycle activities associated with the design, manufacture, and support of these parts, the detailed information needs were identified. The part family consisted of four military F100 engine turbine blades and their associated disks. Table 3-2 provides a breakdown of the selected part family. Table 3-3 illustrates the assembly relationship of each of the turbine blades with its corresponding disk.

TABLE 3-2.

SAMPLE PART FAMILY

Part Name	Engine	Description
Turbine Blade	F100	1st-stage HPT Insert Blade
Turbine Blade	F100-PW-100 F100-PW-200	1st-stage HPT 2 Piece Shower Head Blade
Turbine Blade	F100-PW-220	ILC* 1st-stage Serpentine/film Cooled Blade
Turbine Blade	F100-PW-220	ILC 2nd-stage Radial Flow Blade
Turbine Disk	F100-PW-100 F100-PW-200	1st-stage Turbine Disk
Turbine Disk	F100-PW-220	1st-stage Turbine Disk
Turbine Disk	F100-PW-220	2nd-stage Turbine Disk

* = Improved Life Core

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TABLE 3-3.

ASSEMBLY RELATIONSHIP OF EACH TURBINE BLADE WITH ITS CORRESPONDING DISK

1st-Stage Insert Blade		1st-Stage Showerhead Blade
	1st-Stage Turbine Disk	
1st-Stage ILC Blade	◄	1st-Stage ILC Turbine Disk
2nd-Stage ILC Blade	►	2nd-Stage ILC Turbine Disk

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The external geometry of the selected turbine blades is illustrated in Figures 3-6 and 3-7. Figure 3-6 depicts the concave surface, and Figure 3-7 illustrates the convex surface. Each of the parts contained features that are representative of the level of complexity found throughout the aerospace industry for turbine blades. The blades selected for the walkthrough included the F100 high-pressure turbine 1st-stage insert blade design and the two piece shower head design.

The insert blade illustrated in Figure 3-8 represents the widely used impingement tube design. The primary function of this insert is to enhance the convective cooling of the blade configuration. The tube is designed with an impingement hole scheme, shown in Figure 3-9, which provides high velocity jets of cooling air in regions of high heat flux. The two piece shower head blade illustrated in Figures 3-10 and 3-11 is a newer design that has replaced the insert type. This blade contains an integral cooling scheme which is produced during the investment casting process. This process requires complex wax injection molding dies and ceramic core tooling which are designed and manufactured using a variety of computer based tools. This particular blade is cast at Pratt & Whitney's automated foundry and was selected based on the internal experience developed within Pratt & Whitney manufacturing, as well as for its complex geometry.

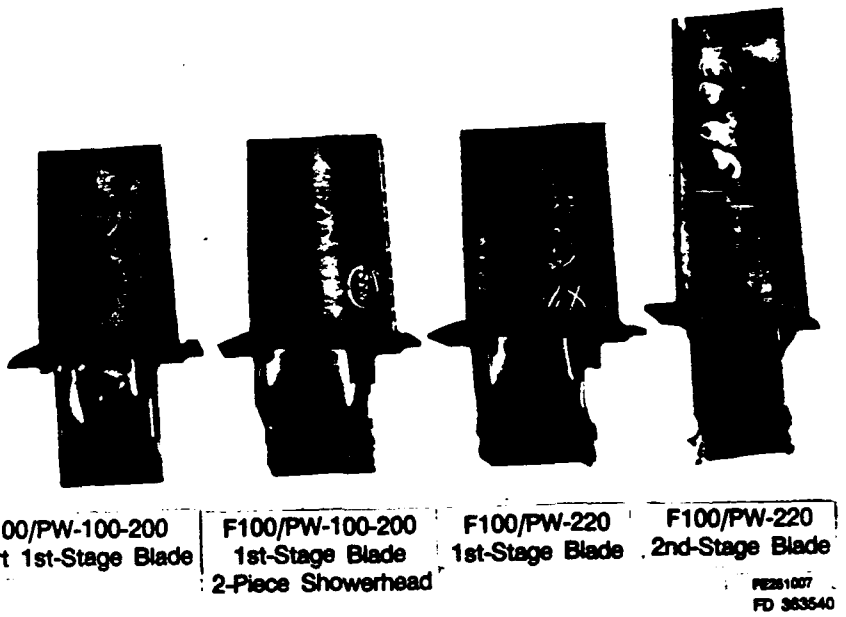

Figure 3-6. Concave Surface of F100 High-Pressure Turbine Blade

Figure 3-7. Convex Surface of F100 High-Pressure Turbine Blade

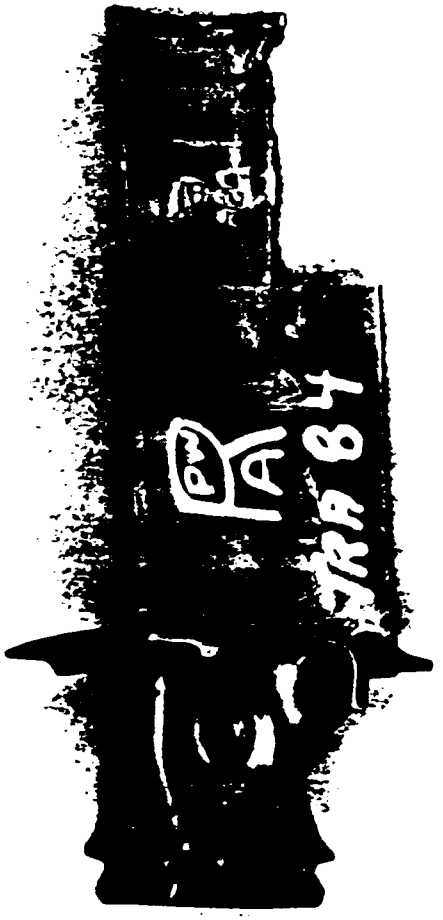

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Figure 3-8. Impingement Tube Design

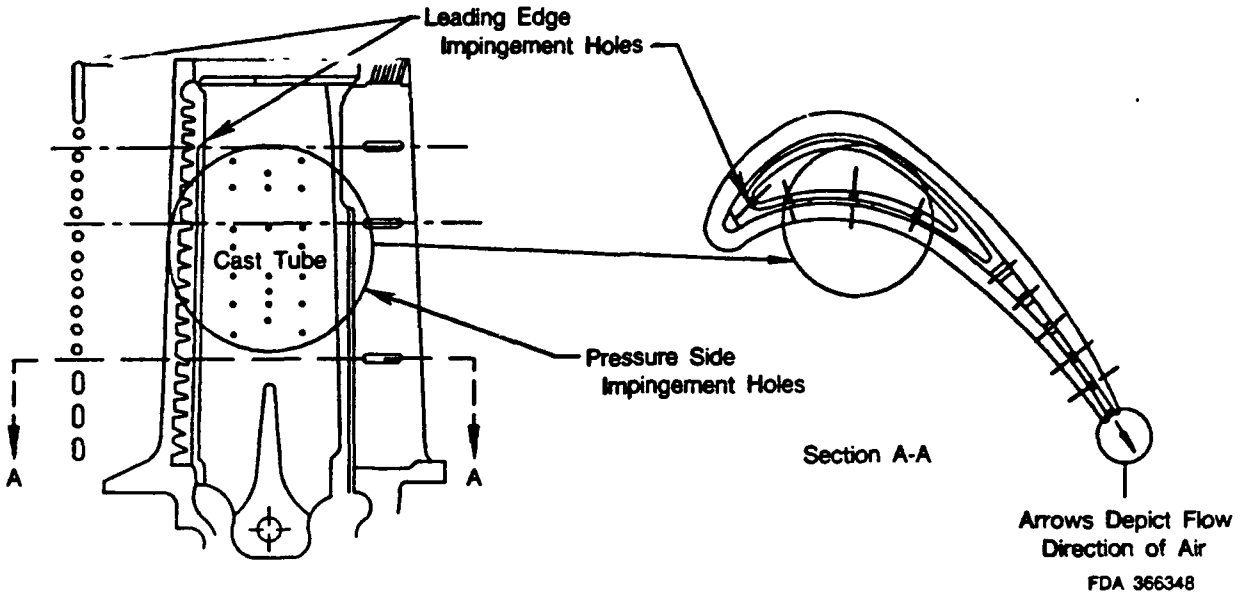

Figure 3-9. Impingement Hole Scheme

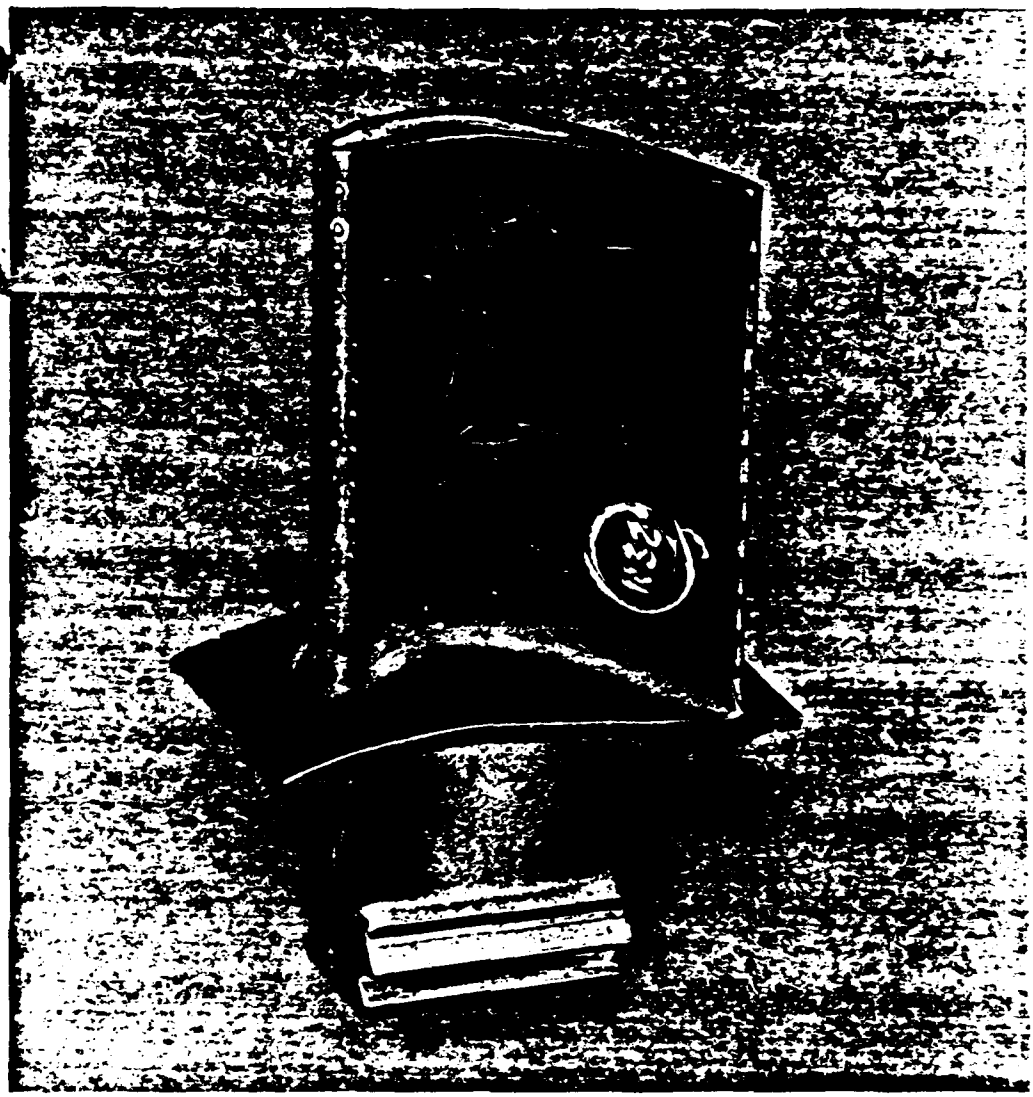

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Figure 3-10. External Design of Two-Piece Showerhead Blade

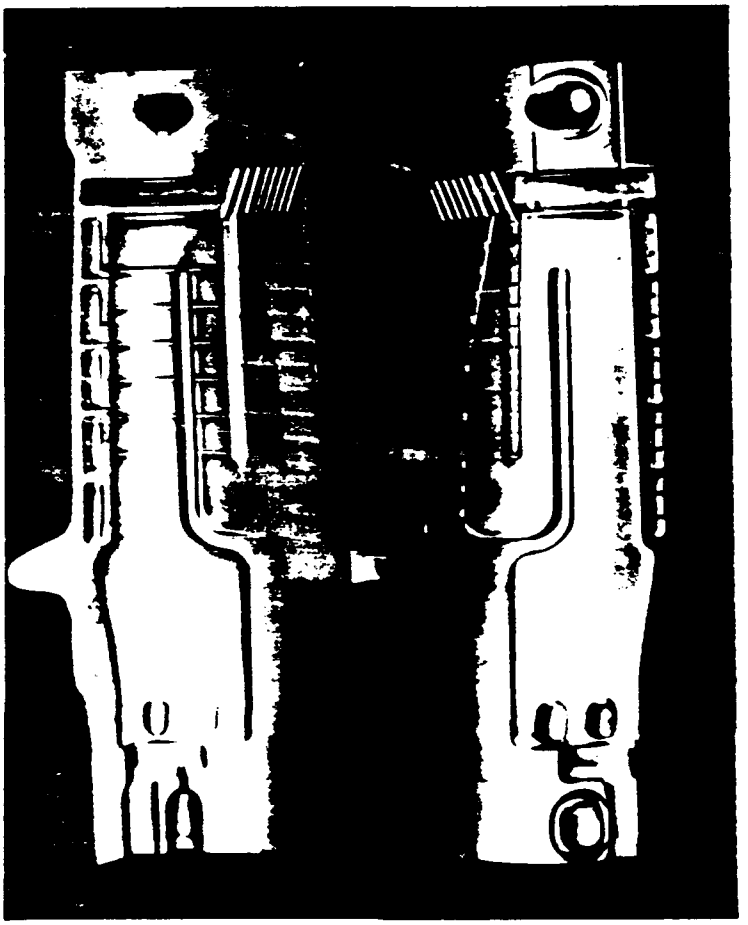

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Figure 3-11. Cutaway View of the Two-Piece Showerhead Blade

The remaining two turbine blade configurations that comprised the sample part family were from the advanced technology F100-PW-220 engine high pressure turbine. This blade was selected because its features represent the full range of simple to complex features and geometry. Figure 3-12 illustrates the complexity of the internal design features of this blade. The internal multipass cooling cavities have two main passages to provide effective distribution of the cooling air. Integrally cast airflow strips are provided on the internal wall of the air passages to increase the convective cooling of the airfoil wall. In critical areas, external film air provides added cooling effectiveness with the use of both round and shaped holes which are produced by electrical discharge machining.

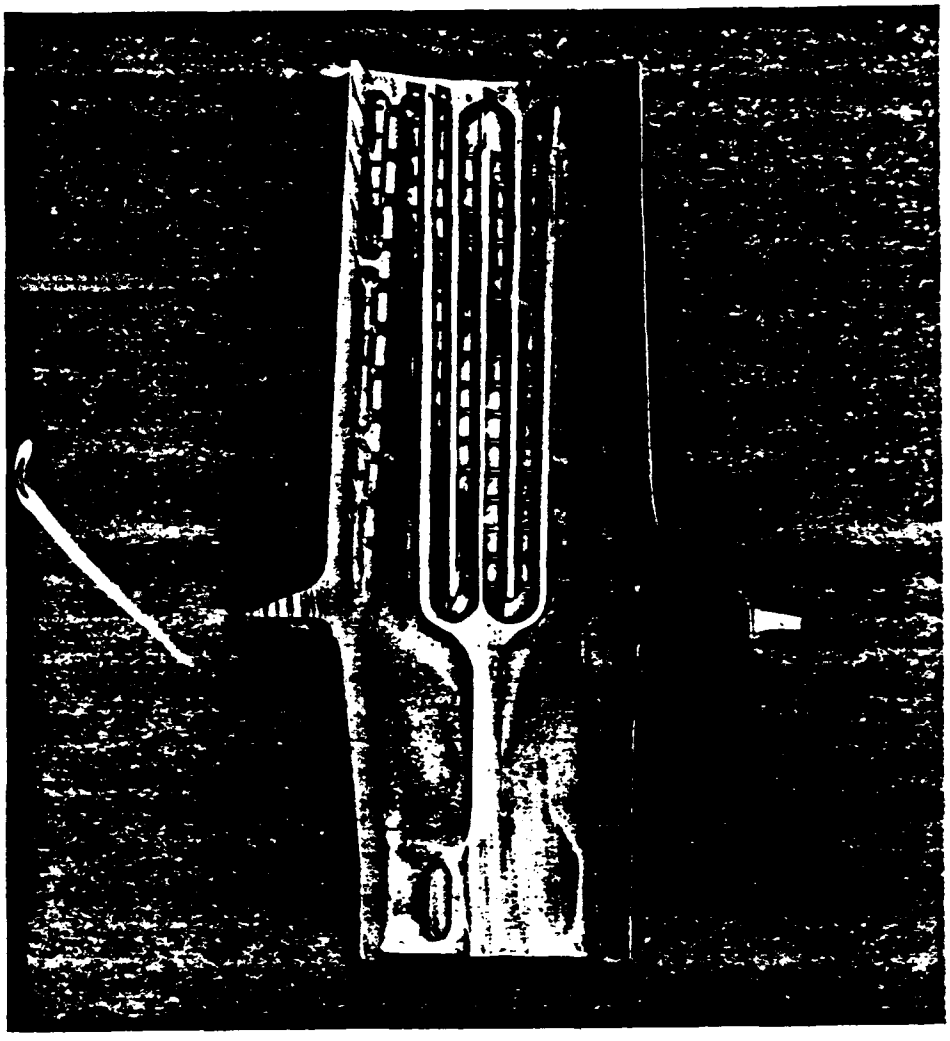

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Figure 3-12. Internal Design of the F100-PW-220 1st-Stage Turbine Blade

The remaining part is the F100-PW-220 2nd-stage turbine blade. The cutaway in Figure 3-13 illustrates the basic design and features incorporated into this configuration.

Three jet engine turbine disks were selected to complete the sample part family. These disks were selected on the basis of forming the 1st-stage assembly with the selected turbine blades. The insert and two piece 1st-stage F100 blades assemble with the disk illustrated in Figure 3-14. The F100-PW-220 blades assemble with the disks illustrated in Figure 3-15. These parts were representative of blades and disks inspected in the Integrated Blade Inspection System (IBIS) and Retirement for Cause (RFC) system.

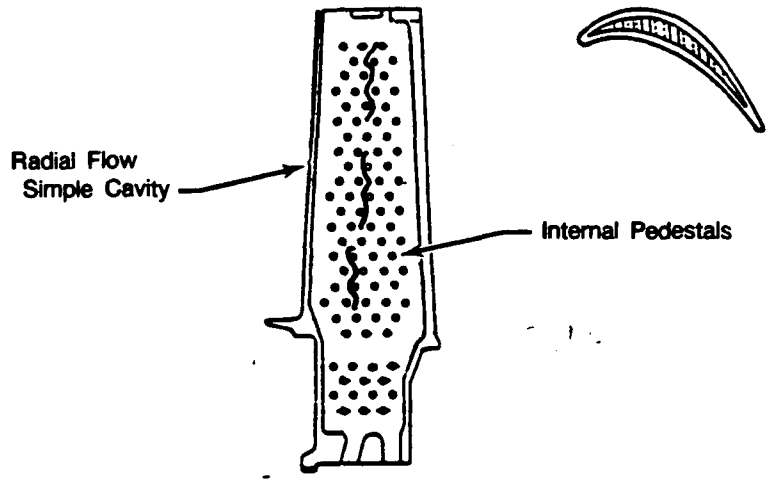

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Figure 3-13. Radial Flow Design of the F100-PW-220 2nd-Stage Turbine Blade

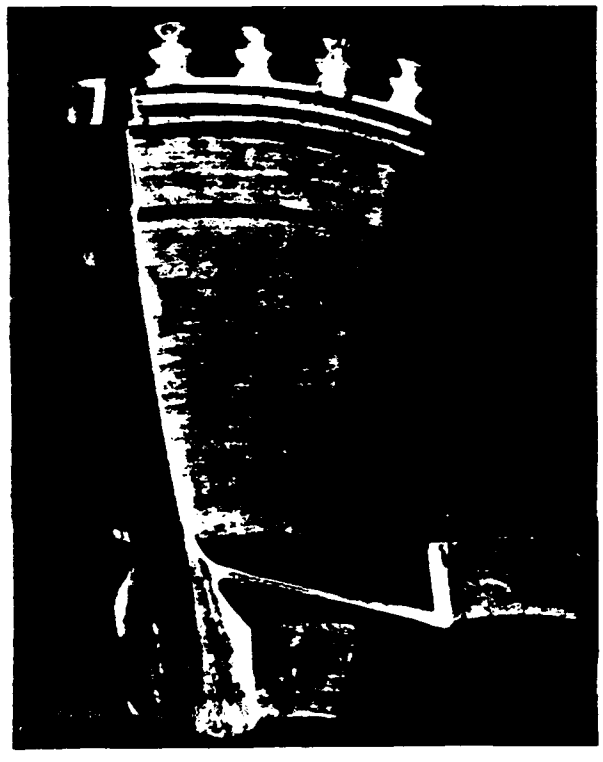

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Figure 3-14. F100 Turbine Disk

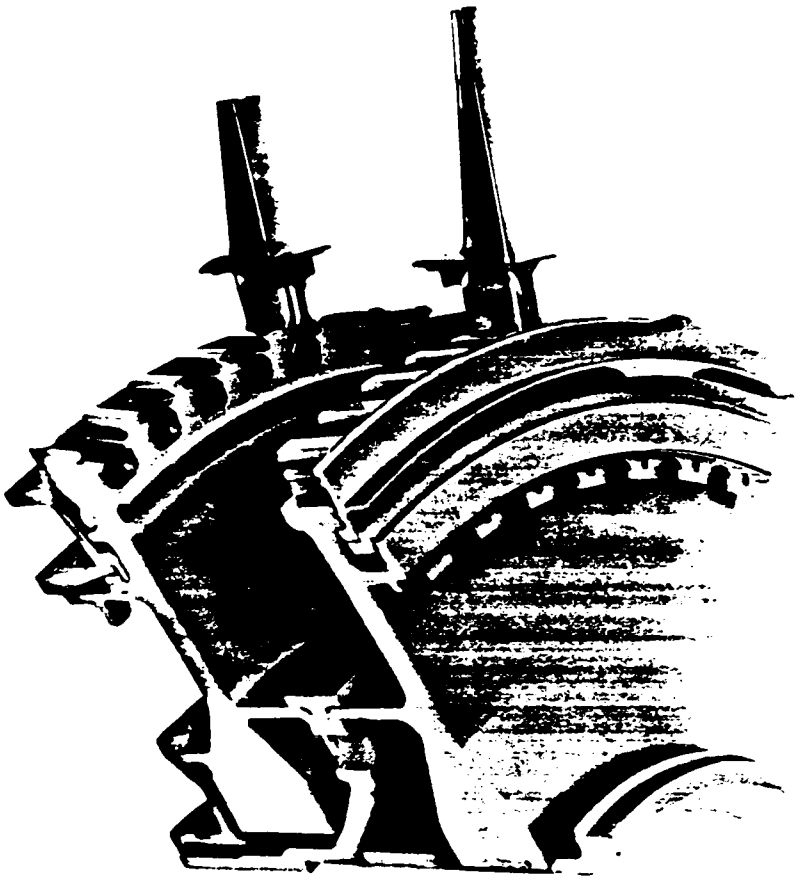

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Figure 3-15. Disks Associated With F100-PW-220 Blades

3.1.1.3.3 GMAP Functional Application Selection

Candidate functional applications for demonstration of GMAP technology were identified by applying IDEF0 modeling techniques during the detailed functional modeling walkthroughs described in Section 3.1.1.3.1. The data requirements of the selected applications were analyzed in subsequent IDEF1 work.

The first level decomposition IDEF0 chart from the scoping efforts illustrated that the functional make-up of the model (including the functions of Manage, Design, Manufacture, and Support) was a logical and functional structure. This was the basis for organizing walkthrough teams.

Three teams were set up, combining the related functions of Design with Analysis; Manufacturing with Inspection; and Product Support with Logistics Support.

Each team had a Principal Investigator responsible for overall GMAP technical work in that area, an expert functional modeler, and an information modeler. The Logistics Support team included the subcontractors responsible for the logistics inspection system phases of GMAP.

The interviews focused on the objectives required for the function modeling to ensure that information transfer from each interview was maximized.

Approximately 100 functional applications were identified, many of which were supported by computer programs: including graphic systems, geometry processors, N/C toolpath utilities, cooling hole laser drilling programs, coordinate measuring machine program generators, finite element stress programs, and tolerance chart programs. General usage exchange mechanisms such as IGES, Information Management Systems (IMS), and Time Sharing Option (TSO) were also identified.

The paragraphs below describe the function modeling efforts and identify the candidate applications for each primary function.

3.1.1.3.3.1 Design and Analysis Walkthroughs

The basic objective of the design and analysis walkthrough was to identify the functional applications used in each area. The walkthrough took place at the Pratt & Whitney facilities in West Palm Beach, Florida. It involved a total of 17 interviews with 29 experts from various discipline areas.

In design and analysis, the amount of computerization and electronic interface ranged from complete to partial. This area created the PDD that is carried in both electronic and paper forms. The walkthrough also showed that several specific design and analysis disciplines worked together to produce a final part design.

Preliminary Design

Preliminary designers translated the customer's requirements into design criteria and design tables that detailed engineering processes used as input. They establish engine configuration, power, performance, life, and operating temperatures. This iterative process involved people from several engineering groups, and did not result in a final part definition.

Aerodynamic Design

Aerodynamic design used the design tables as input, developed the turbine airstream flowpath through steps of design and analysis in tight internal loops, and ended up with a series of 2-D airfoil profiles. Aerodynamic design also establishes a flowpath, meanline design, and a streamline design.

This area was highly automated, such that the output of one program became the input to the next. The level of PDD involved was not great, but the output (the data points on the external surface of the airfoil) of the discipline was the first product defining data that was seen.

Durability Design

Durability design was responsible for the cooling design of turbine blades. The task focused on developing a cooling scheme, calculating the required flow, developing core geometry, and locating cooling film holes. The process involved the use of heat transfer, stress, flow, and finite element analyses.

This area was moderately computerized, but not as sequential as aerodynamics. The rate of technology evolution in turbine design, and therefore, cooling scheme complexity, has led this discipline away from traditionally effective applications. It required manual data manipulation or new computer applications.

Structures Technology

The structures group performed in-depth analyses when the design became mature. These verification analyses were complicated and time consuming, and tests ranged from generic statistical analyses, through finite element modeling, to specific life calculations. Design verification analyses included creep-rupture, crack growth, fracture mechanics and the full spectrum of plastic and elastic stress analyses.

This discipline was highly automated, and the data defining the material and geometry of the part was the main input. However, an extensive integrated computerized interface did not exist between the structures people and the component designers.

Mechanical Design for Blades

The mechanical designer was ultimately responsible for the part design. For turbine blades, 3-D models were created from the internal and external cross-sections. This was to evaluate the breakout between holes and surfaces as designed, and often required iteration. The mechanical designers also developed the design of the blade platform geometry and the transition from the airfoil to the platform. Blade geometry below the platform was also developed here; the internal cooling passage, and the external shank geometry. The mechanical designer continued to define the blade further, and developed the mass property analysis.

Mechanical Design for Disks

Disks were designed in the mechanical design area. The mission requirement limitations and other design criteria from preliminary design were used to produce a preliminary disk profile. This profile was then analyzed and optimized. The disk broach geometry was designed from the given blade mass properties. This configuration was banded to produce the final blade attachment geometry.

Drafting

The drafting area had the responsibility to communicate the design intent. This included converting the as-designed hot dimensions to the as-made cold dimensions. In doing this, the critical design tolerances were reviewed and dimensioning was established. The drafting area assisted in developing the core transition from airfoil to attachment in a 3-D model. Several CAD/CAM files were derived, produced, and included in the design review process.

Design Review

The entire design process was finalized at a Design Review. The complete spectrum of interests involved with that part played decisive roles in the approval process. The disciplines concerned included aerodynamics, durability, structures, drafting, producibility, inspectability, metallurgy, and quality assurance.

Walkthrough Results

This walkthrough resulted in a function model that identified potential applications that were later investigated during the information modeling. At the lowest functional level, the mechanisms identified were indeed application programs, and thus, the model terminated at this level.

The full list of functional computer applications identified by the design and analysis walkthrough is shown in Table 3-4. More than enough applications from the disciplines involved were identified, and there was comprehensive coverage of the part life cycle.

3.1.1.3.3.2 Manufacturing and Inspection Walkthroughs

Identification of manufacturing and inspection candidate functional applications also occurred with the IDEF0 analysis described previously. The manufacturing and inspection walkthroughs were conducted at five different facilities throughout Connecticut and in Georgia. These facilities illustrated the diversity and decentralization of the manufacturing effort:

- **Automated Casting Facility, Middletown, Connecticut.** Highly automated, this facility produced castings for the F100 1st-stage turbine blade (shower-head configuration). This was the only turbine blade in the sample part family cast by Pratt & Whitney. All of the other turbine blades were cast by suppliers.

- **Experimental Foundry Facility, Manchester, Connecticut.** This facility developed new casting technologies to support advanced turbine blade designs. It was heavily involved in developing the casting processes used at the Automated Casting Facility in Middletown, Connecticut.

- **Columbus, Georgia.** This facility was responsible for high technology forging of the F100 high pressure turbine disks. It was also responsible for the initial (sonic shape) machining and ultrasonic inspection of these parts. The facility was highly automated and had a number of computerized applications suitable for data analysis and possible GMAP demonstrations.

- **North Haven, Connecticut.** All parts in the sample part family were machined and finished at this facility. It performed many functions on the parts such as grinding, turning, milling, broaching, coating, and final inspection.

- **East Hartford, Connecticut.** All centralized functions within the Pratt & Whitney manufacturing environment were performed at this facility. It provided key technical and administrative support functions, along with assembly of the blades and disks.

TABLE 3-4.

DESIGN AND ANALYSIS FUNCTIONAL APPLICATONS

Preliminary Design
— State-of-the-art Performance Program
— Parametric Engine Program-12 Vehicle Analysis Mission Program

Aerodynamic Design
— Flowpath Generator/Parameter Solver
— Meanline Design
— Streamline Design
— Airfoil Design
— Curved Line Fairing and Stress
— Transonic Potential Flow — Pressure Distribution
— Boundary Layer Analysis
— 3-D Time Marching Pressure Distribution
- Internal Geometry Definition

Durability Design
— Internal Flow Program
— Heat Transfer Program
— Finite Element Breakup Program
— Stress Analysis
— Mission Life Proration
— Creep-Rupture Life Evaluation/Low-Cycle Fatigue (LCF) Life Evaluation
— Curved Line Fairing and Stress

Structures
— Plane Elasticity Integral Equation Analysis
— Generalized 2-D and 3-D Finite Element Static and Dynamic Stress
— Generalized Disk Stress Analysis
— Generalized Shell Program
— Biaxial Stress Distribution in Disk Rim Slots
— 2-D and 3-D Nonlinear Elastic Analysis of Solids, Shells, and Beams
— Temperature Averaging Program
— Curved Line Fairing and Stress
— LCF Regression Data Program
— Variable Reduction Program
— Statistical Analysis System
— LCF Life Prediction Routine
— LCF Life Prediction Program
— Through—Crack Predictions at Stress Concentration Regions
— General Purpose Spectrum Loading Program
— Tension and Bending Crack Growth Program
— Linear Elastic Fracture Mechanics Program
— Preliminary Disk Profile Generator

TABLE 3-4.

DESIGN AND ANALYSIS FUNCTIONAL APPLICATONS (CONTINUED)

Mechanical Design
— Cycle and Stress Program
— Fir-Tree Synthesis
— Preliminary Disk Profile Generator
— Mission Analysis Program
— Elastic Stress Program
— Temperature Averaging Program
— Finite Element Stress Analysis

Drafting
— Computer Graphics System A (Drafting)
— Computer Graphics System B (Drafting)
— Curved Line Fairing and Stress
— EMD Generator Interface
— 2-D Geometry Processor
— Airfoil Drafting Utilities
— Cooling Hole Pattern Generator
— Point Redistribution Program
— Airfoil Manipulation Programs

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Manufacturing was broken into six major functions that were investigated to identify and track the use of PDD. The major functions, illustrated in Figure 3-16, are briefly described below.

- "Plan for Manufacture" was the overall planning and integration process within the manufacturing function. It consisted of activities such as developing production start-up plans, sourcing, integration, and monitoring overall performance. It was primarily an administrative function and was a conduit of PDD.

- "Make and Administer Schedules and Budgets" provided preliminary schedules and budgets and refined them as production details were supplied from the "Plan Production" function.

- "Plan Production" was the key technical and engineering function and, as such, was the primary user of PDD. Results of the walkthroughs indicate that all other major functions relied on this function as the primary source of technical information relative to the manufacturing process. This function was responsible for:

    - Planning and scheduling production methods

    - Providing and documenting manufacturing and inspection instructions

    - Developing tooling requirements and providing tool designs

  - Programming all automated manufacturing and inspection devices

  - Providing technical liaison with design engineering and with tooling suppliers.

- "Provide Production Resources" provided facilities, equipment, tooling, and personnel to manufacture the product. It was primarily an administrative function and relied on the "Plan Production" function for technical information and analysis.

- "Obtain Manufacturing Materials" included all phases of material acquisition from purchasing through in-house storage and distribution.

- "Produce Engine Product" included the actual manufacturing and inspection of engines, parts, and spares. It was also a primary user of PDD. However, the results of the walkthroughs showed that it relied on the "Plan Production" function as its primary source of PDD and for technical instructions.

Walkthrough Results

In general, it was found that manufacturing functions were decentralized and highly dispersed. Manufacturing functions associated with the sample part family were distributed among the five different facilities. This did not include the role of suppliers. While this presented a significant logistical problem in accomplishing the walkthroughs, it also pointed out a benefit to using electronic PDD. Almost all of the interviewees indicated a primary need to access this kind of information on the computer, rather than rely on the flow of paper.

Manufacturing was characterized by islands of automation. A number of the facilities, such as the Automated Casting Facility and the Columbus, Georgia facility, were highly automated, while others were not. Further, some functions, such as N/C programming and dimensional inspection, were highly automated while other key functions were not.

Suppliers were highly involved in the manufacturing process. They had a principal role in the production of the following:

- Airfoil castings
- Disk forgings
- Raw materials
- Design and development of production tooling.

Interviewees responsible for dealing with suppliers generally indicated that electronic PDD would benefit suppliers using CAD/CAM equipment and would provide an incentive to those suppliers which did not currently use this equipment.

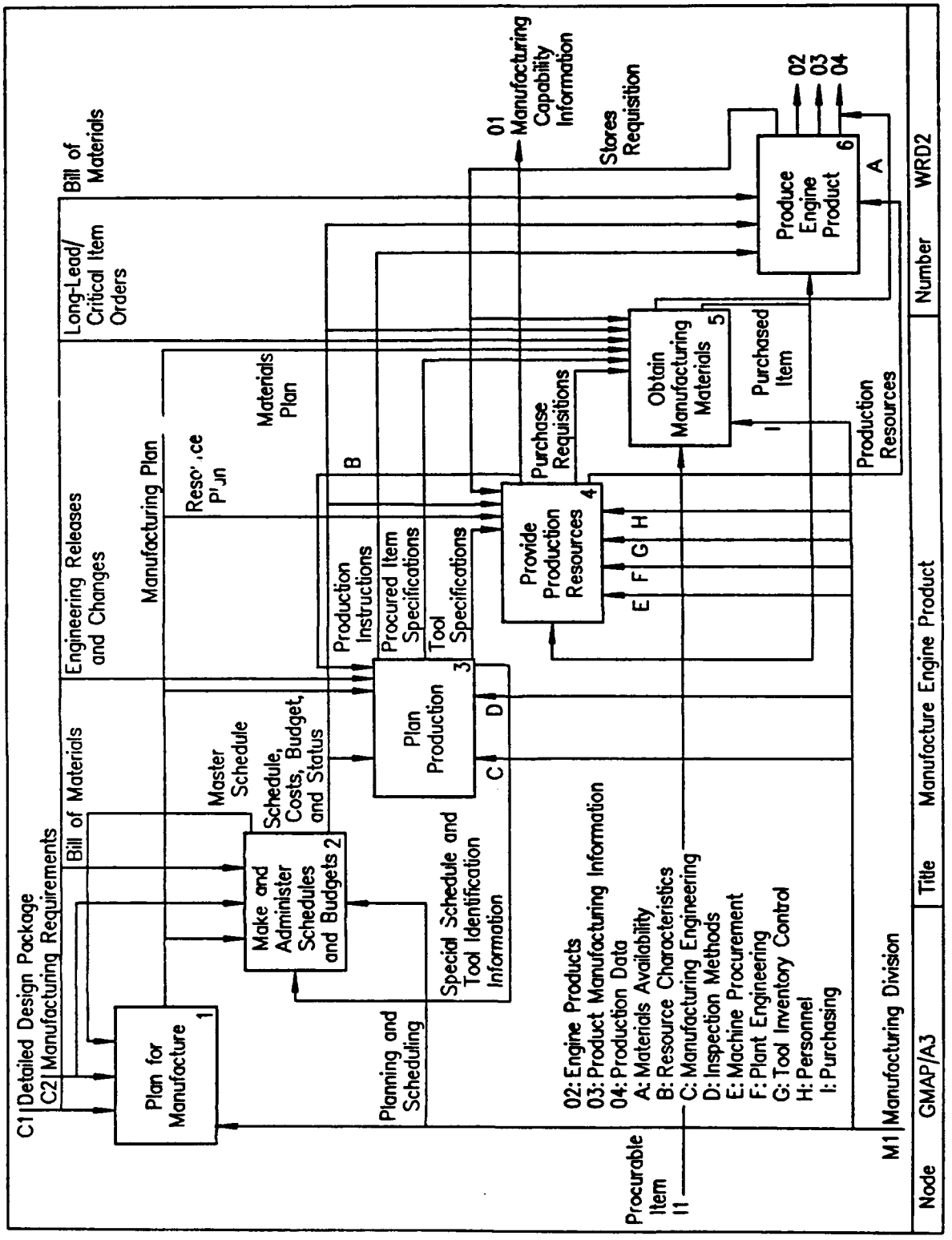

Figure 3-16. Manufacture Engine Product

Production planning was the key function in the development and use of PDD. The walkthroughs identified this function as the key technical and engineering function within manufacturing. All of the other functions relied on production planning as their primary source of technical information and analysis.

The manufacturing and inspection walkthroughs identified the key functions listed in Table 3-5 as those that should be included in the information modeling analysis.

TABLE 3-5.

MANUFACTURING AND INSPECTION FUNCTIONAL APPLICATIONS

Manufacturing
— Computer Aided Process Planning
— Tolerance Chart Program
— Computer Graphics Systsm A (N/C)
— Computer Graphics System B (N/C)
— Airfoil Manipulation Programs
— 2-D Geometry Processor
— Turning Interactive Program (N/C)
— Automatically Programmed Tools (N/C)
— N/C Toolpath Plotting Utility
— N/C Cooling Hole Laser Drilling Program Generator
Inspection
— 2-D Geometry Processor
— Coordinate Measuring Machine Program Generator
— Scan Program Generator
General Usage
— Network Communications Package
— IGES
— Inter-Divisional Exchange System
— Information Management System
— Time-Sharing Option

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3.1.1.3.3.3 Product Support and Logistics Support Walkthroughs

Product Support

As with the other two groups, the IDEF0 functional modeling approach was used in walkthroughs of Pratt & Whitney's product support functions.

Product Support consisted of all support activities necessary to service Pratt & Whitney engine customers. It provided technical information and instructions, processed warranty claims, provided pricing information, processed orders for spare parts, established logistic requirements, and forecast future parts needs.

The Product Support walkthrough showed that there were four major activities, illustrated in Figure 3-17, necessary to provide customer service. These activities were: Provide Technical

Support, Process Spare Parts Orders, Determine Logistics Needs of the Customer, and Plan Future Spare Parts Requirements.

- "Provide Technical Support" was performed by the technical support staff and included all the technical, logistic, repair, and equipment support activities. This function involved all customer-related technical problems. It also included designing special ground support equipment, establishing and administering the warranty program, and turning out the finished technical orders.

- "Sell Spare Parts" was performed by the spare part sales staff dealing with customer requests for parts and information. This function included responding to customer queries and order requests as well as the processing of orders for spare parts and equipment.

- "Determine Customer Logistics Needs" was performed by the technical support staff and involved an assessment of customer repair requirements compared to current capabilities. This information was used to determine any shortfall of material or equipment required to support maintenance or repair of engines. It comprised an analysis of customer orders and product information, a review of ground support equipment designs and customer capabilities to identify logistic needs, and documentation of logistics support requirements.

- "Provide Spare Parts Planning" was performed by the spare parts sales staff and involved all planning related to providing spare parts. This function included creating a forecast of spare parts demand, preparing a master forecast for production scheduling, and providing price lists and specific price quotations.

Logistics Support

The walkthrough methodology was used to examine logistics support in general, and to study two specific areas within logistics dealing with inspection processes. One dealt with blades, the Integrated Blade Inspection System (IBIS); the other with disks, Retirement for Cause (RFC). The general walkthrough was conducted at SA-ALC at Kelly Air Force Base, San Antonio, Texas. The two specific studies were based on discussions with personnel at Systems Research Laboratories, in Dayton, Ohio, and at General Electric, in Evandale, Ohio as well as from information gathered at SA-ALC.

The general analysis of the logistics support functions was conducted first. The goal of this portion of the walkthrough was to understand product maintenance activities performed by users in the field.

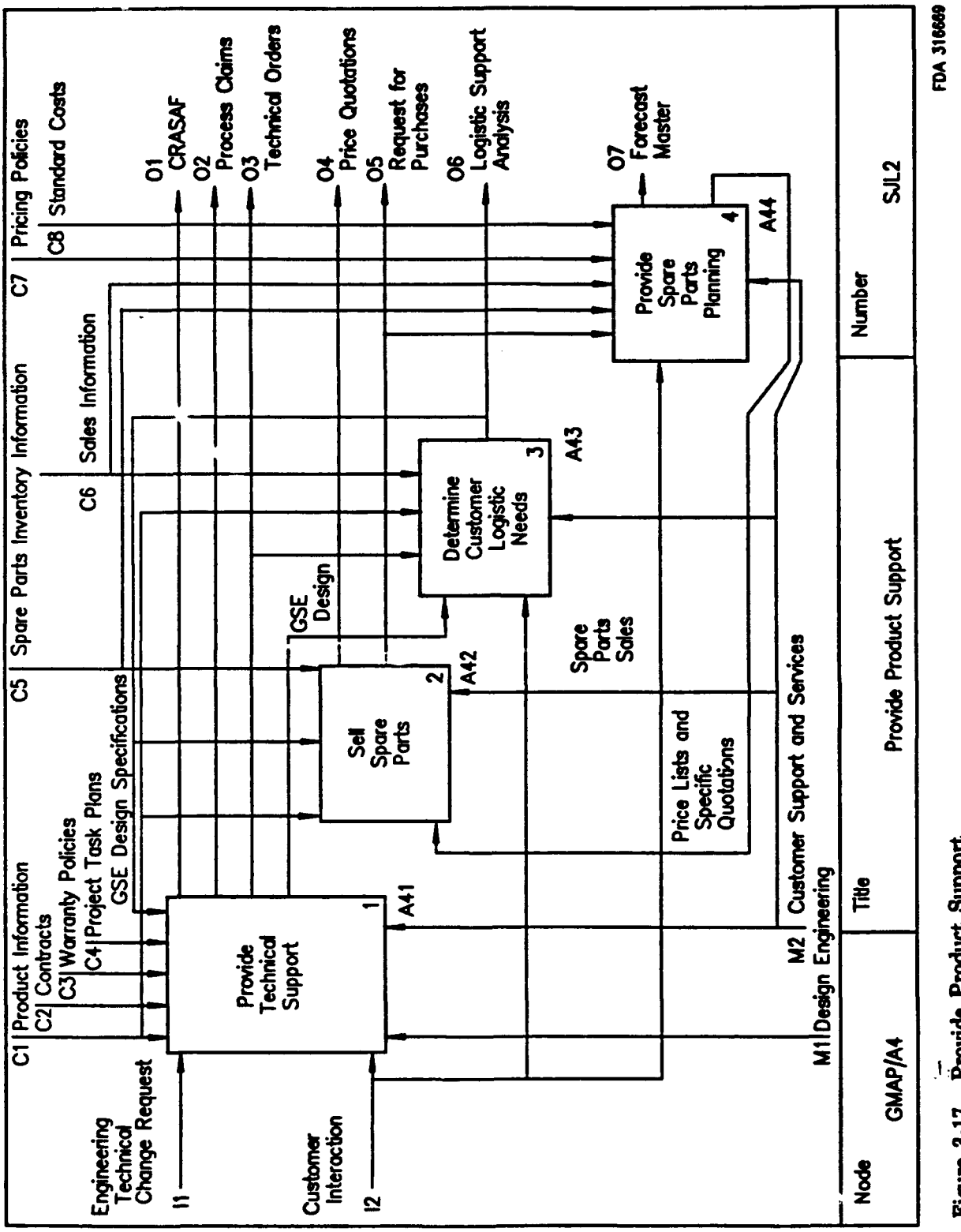

Figure 3-17. Provide Product Support

R30802/3

Logistics support involved the disassembly, inspection, service, repair, and reassembly of in-service aerospace products. The primary concern of the GMAP analysis was the return of serviced products to operation. The term "product" was used to include the aerospace product as well as the supporting systems.

Logistics support at the SA-ALC was found to consist of five major activities: Management; Planning; Schedules and Budgets Administration; Product Maintenance; and Assembly and Test. The major area emphasized during the walkthrough was Product Maintenance.

Product Maintenance encompassed the actual hands-on maintenance. Component disassembly, inspection, and repair and/or retirement. The investigation of the Product Maintenance area uncovered the four major activities shown in Figure 3-18: Planning; Provide Maintenance Resources; Obtain Maintenance Materials; and Perform Actual Maintenance.

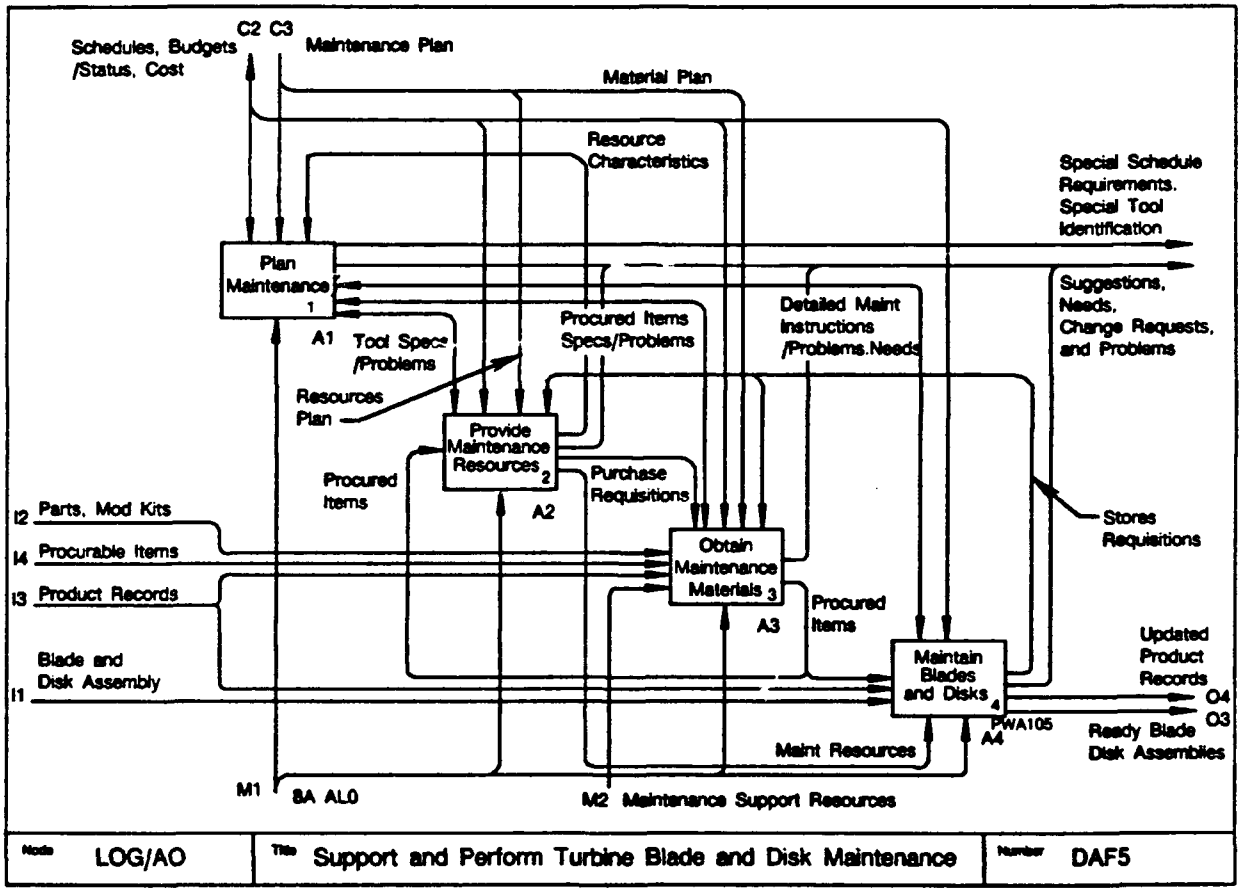

Figure 3-18. Support and Perform Turbine Blade and Disk Maintenance

Planning, Provide Maintenance Resources, and Obtain Maintenance Materials closely resembled the activities of a manufacturing facility. Detailed maintenance instructions were created to guide maintenance processes. The majority of these instructions were created

manually, derived from information obtained from engineering drawings and from technical orders supplied by the manufacturer.

IBIS

IBIS provided an automated blade inspection capability for the logistics support facility. It was a more repeatable and less subjective inspection with increased capability. It also allowed inspection to keep pace with the technological advances in jet-engine blade design and manufacture.

IBIS consisted of several of distinct, integrated submodules. There were three inspection submodules, illustrated in Figure 3-19, that performed the actual inspection. These were the Fluorescent Penetrant Inspection Module, the Infrared Inspection Module, and the X-Ray Inspection Module. In addition, the Information Computer System was the manager of inspection data and inspection results. The Automated Fluorescent Penetrant Pre-Processing Module automated the application of fluorescent penetrant to parts that were to be inspected with the Fluorescent Penetrant Inspection Module. This helped to ensure consistent and accurate fluorescent penetrant inspections.

RFC Inspection System

The RFC system was an automated, robotics-based inspection system developed by Systems Research Laboratories in Dayton, Ohio for the SA-ALC. RFC was used to detect engine disk surface and internal flaws using eddy current and ultrasonic Nondestructive Evaluation techniques.

RFC extended the life of parts by measuring and evaluating actual in-service flaw sizes. These measured flaw sizes were used as the basis for retiring disks, as opposed to using conservative engineering predictions.

The RFC system consisted of two automated cells. One cell used an eddy current instrument and technique to detect surface flaws. The second cell used an ultrasonic instrument to detect subsurface flaws.

The RFC system major functions included generating a scan plan for the inspection of disks and creating an analysis software package to analyze the inspection data. The analysis determined the disks status — accept, reject, or incomplete. The process is graphically depicted in Figure 3-20.

3.1.1.3.4 Establish Coordination With Other CIM Projects

Pratt & Whitney investigated other Air Force Materials Lab CIM Branch programs as well as industry efforts in an attempt to establish technology transfer opportunities. Coordination of GMAP with projects with similar objectives would provide additional direction to the program and enable GMAP to reap the benefits of similar work completed or in process.

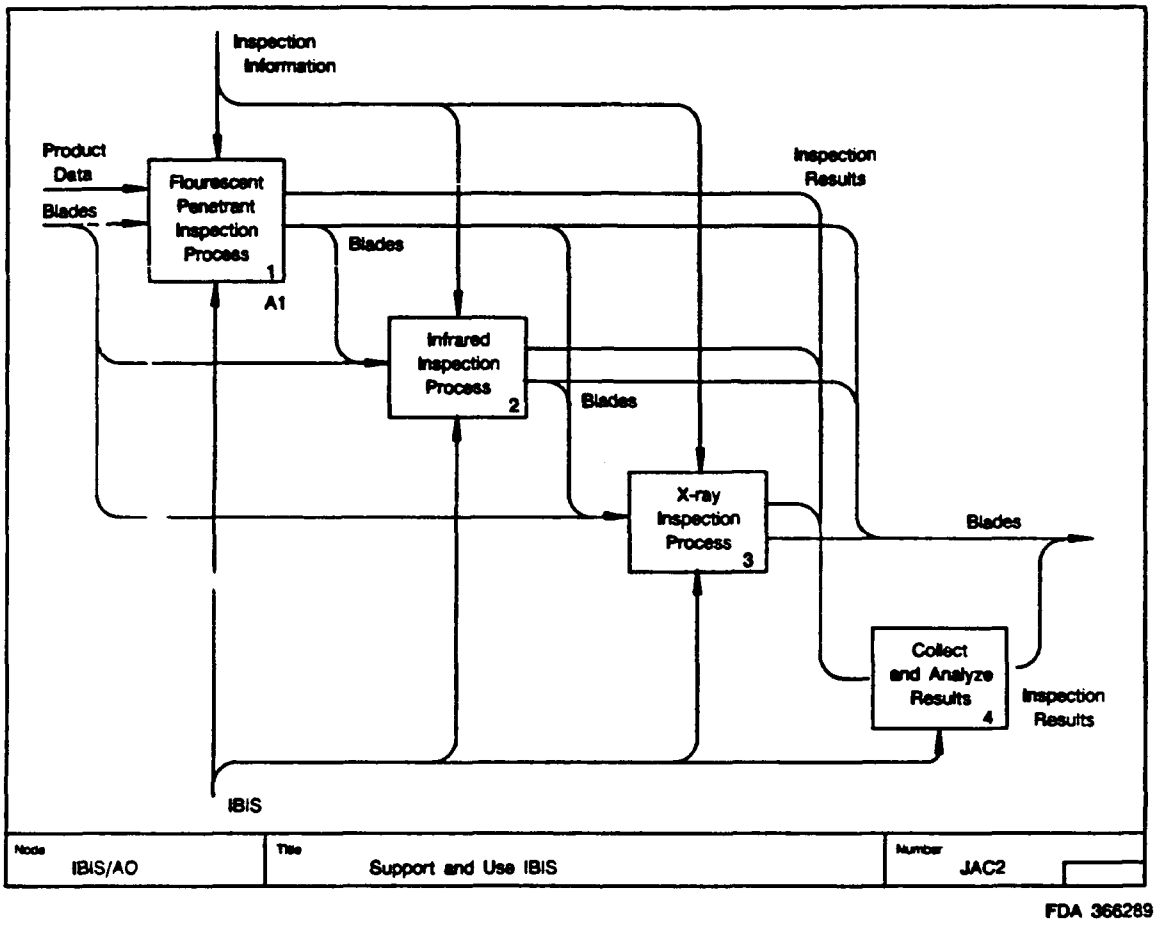

Figure 3-19. Support and Use IBIS

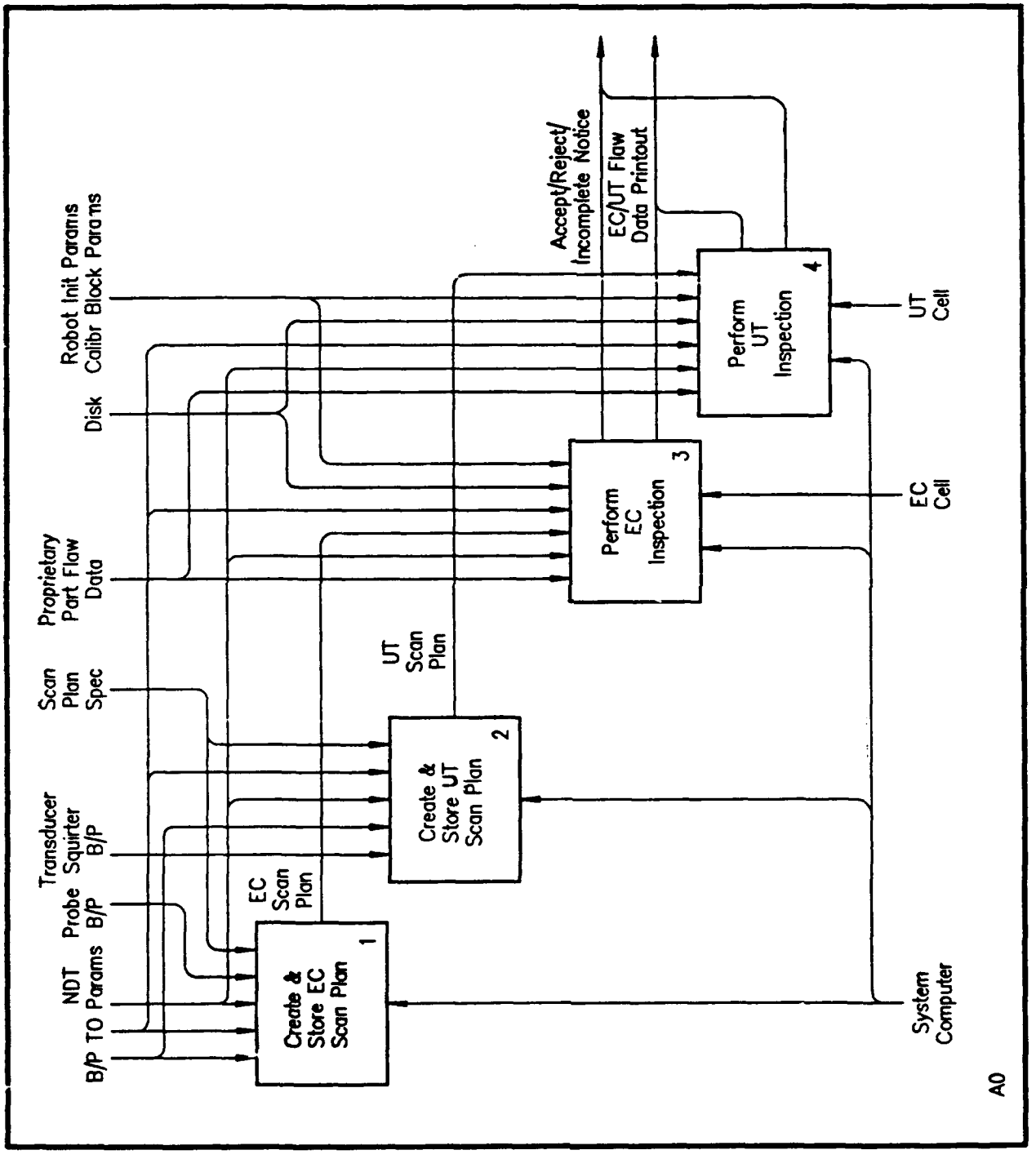

Figure 3-20. Perform Retirement for Cause

R20802/3

Initially, GMAP looked at several programs including:

- Product Definition Data Interface (PDDI)
- Integrated Information Support System (IISS)
- Intelligent Task Automation (ITA)
- Factory of the Future (FOF)
- National Bureau of Standards', later changed to the National Institute of Standards and Technology (NIST), Initial Graphics Exchange Specification and Product Data Exchange Specification (IGES/PDES)
- Computer Aided Manufacturing-International (CAM-I)
- Integrated Design Support System (IDS).

The process of identifying the most appropriate projects led the GMAP team to concentrate on PDDI and NIST associated programs. Appendix B presents a compendium of the various technology transfer efforts conducted.

3.1.1.4 Industry Review Board

An Industry Review Board (IRB) was established to:

- Review the progress of GMAP
- Assess the technical direction of the project
- Offer advice from a broad base of industrial background and experience
- Provide an important vehicle to assist with the transfer of GMAP technology to industry in general.

3.1.1.4.1 Membership

Pratt & Whitney solicited several organizations to become members of the IRB. The IRB originally consisted of 12 member organizations — three from each of four categories: gas turbine engine manufacturers, airframe manufacturers, computer system manufacturers, and major gas turbine engine subcontractors. As the program evolved, some members withdrew for various reasons and others were added. The final makeup of the IRB is presented in Table 3-6.

TABLE 3-6.

IRB MEMBERSHIP

Chairman	**Members**
Mr. George J. Hess	Jim Hutto
Ingersoll Milling Machine Co.	Intergraph Corporation
Secretary	Chris Klomp and Mile McClure
Jason (Jack) Lemon	Boeing Company
International TechneGroup Incorporated	
	Robert Krakowsky and Stan Pickford
Members	Wyman-Gordon Company
Robert Badgett	
ComputerVision Corporation	Don Manor
	Deere & Company
Jack Conaway and Ulrick Flatau	
Digital Equipment Corporation	Robert L. McMahon, Jr.
	General Dynamics
Calvin W. Emmerson	
Allison Gas Turbine Division	Donald Moracz
	Textron M&MTC
S. J. (Jeane) Ford	
International TechneGroup Inc.	Chet Moutrie
	Control Data Corporation
Donald J. Gregory	
General Electric/AEBG	Ed Schumacker
	Avco Aerostructures Textron

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Mr. G. Hess, Vice President — Systems and Planning for Ingersoll Milling Machine Company, agreed to be the Chairman of the IRB. Mr. Hess joined Ingersoll in 1974 to manage all systems and data processing, and was elected vice president in 1981. Under Mr. Hess's leadership, Ingersoll was chosen as the recipient for the second annual "LEAD" award in 1982 by the computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME). Mr. J. Lemon, President of ITI, agreed to be Secretary of the IRB.

3.1.1.4.2 Strategies

There were several strategies used to assure a successful IRB. First, since the GMAP IRB was also the forum to provide industry feedback to the extension of the PDDI project, there was an overlapping of members. That is, the GMAP IRB contained some members from the PDDI IRB.

Also, a member was selected who could provide an effective interfece to the NIST PDES program. It was expected that GMAP would be able to contribute to PDES in PDD related areas such as file size, processing speed, functionality of information, elimination of redundancy.

The IRB representative from each of the participating companies was expected to provide additional people from his or her firm that have expertise in the agenda material being discussed.

R20602/3

3.1.1.4.3 IRB Meetings

There were six IRB meetings. Each meeting reviewed the technical progress of the program and provided a forum for technical guidance. The meetings took place in the time frames, with topic areas as indicated in Table 3-7.

TABLE 3-7.

IRB MEETINGS

Date	Topic
1. February 1986	Review technical approach and scoping
2. September 1986	Review Needs Analysis Work, State-of-the-Art findings, and technical progress
3. March 1987	Review Task 1 documents, interface plans, and design approaches
4. December 1987	Review minimum requirements of a product modeler and related issues
5. March 1988	End of PDDI Extension debriefing
6. September 1988	Review results and lessons learned

R20802/15

3.1.1.4.3.1 First IRB Meeting

The first IRB meeting was held February 5 and 6, 1986, in West Palm Beach, Florida. The meeting, attended by approximately 60 people, was divided into six sessions. Session one was an introductory session, with welcoming remarks and introductions of the members and observers. The group was briefed on the purpose for the board and given a general overview of the program.

Session two focused on the roles of the subcontractors, program objectives and anticipated results from the first two tasks.

Session three concentrated on understanding the features of the product family of the program and correlation with PDD and geometric representation. An overview of the walkthrough methodology was presented in this session.

The fourth session focused on the results of the IDEF0 part walkthrcughs for Engineering and Manufacturing. The session also presented the status of Task 1.

Session five provided details, plans, and status for the state-of-the-art (SOA) survey and the documentation on the Minimum Requirements for a Geometric Modeler. Attendants were also briefed on the work planned and status for the RFC and IBIS logistics applications.

Session six was devoted to the IRB's membership providing input and direction for the program. The group was divided into four smaller groups, and each was asked to address an issue

that the GMAP team felt could have an impact on the program. All comments received were very favorable, and all present were pleased with the two-way communication and interaction of the group.

3.1.1.4.3.2 Second IRB Meeting

The second IRB meeting was held 9 and 10 September 1986 in Hartford, Connecticut. The meeting was attended by approximately 100 people representing a broad cross section of American industry. Included were: aerospace and nonaerospace firms, computer manufacturers, CAD/CAM suppliers, universities, and the military. The primary theme of the meeting was to present findings of the walkthroughs and show the needs for the selected part family.

The meeting was divided into seven sessions. Session one featured welcoming remarks and introductions of the IRB Chairman, Mr. G. Hess. The group was briefed on the status of the program, followed by a review of the last IRB meeting, presented by IRB secretary Mr. J. Lemon from International TechneGroup Incorporated (ITI).

Session two focused on the walkthrough investigation that was conducted for the needs analysis. Presentations were given on the life cycle functional areas investigated: Design and Analysis, Manufacturing and Inspection, Product Support, and Logistic Support. These presentations reviewed the as-is environment, discussed the to-be environment, and indicated what PDD needs had to be met.

Session three detailed the data needs and presented the categorized classes established during the modeling efforts. These classes were: Geometry, Topology, Features, Tolerance, Nonshape and Notes, and Administrative and Assembly.

The fourth session was a workshop which provided the IRB members and observers with a chance to interact on issues surrounding the needs analysis. Six groups were formed and were asked to address specific issues that could impact the program.

Session five was an overview on the initial findings of the State-of-the-Art (SOA) survey.

Session six was devoted to presentations on other programs that were related to GMAP. These efforts included: Computer-aided Acquisition and Logistics Support (CALS), NIST, IGES/PDES, and American National Standards Institute (ANSI) Y14.26. The last session provided an overview of the PDDI extension contract.

3.1.1.4.3.3 Third IRB Meeting

The third IRB meeting was held 29 and 30 April in Deerfield Beach, Florida. This meeting was attended by approximately 75 people representing organizations similar to those at meeting 2. The primary objective of the meeting was to review the GMAP conceptual design. Other major items included presentations on both the proposed demonstrations for GMAP and the PDDI extension contract.

The meeting was divided into five sessions. Session one featured opening remarks from Mr. R. Lopatka, Pratt & Whitney's GMAP Program Manager. The IRB Chairman then provided welcoming remarks and introduced the IRB members and observers. Lt. E. Gunther, the new

United States Air Force (USAF) GMAP Program Manager, followed with a welcome to all attendants. This session ended with a presentation on the current status of the GMAP contract which included a briefing on the technical progress that occurred since the September 1986 IRB meeting.

Session two consisted of two presentations that completed the technical work in Task 1 of GMAP. The first of these was a final report on the SOA survey. It focused on current technology, needed technology, technology trends, and analysis results. The second Task 1 presentation was a report on the minimum product modeler required to support the jet engine turbine blade and disk life-cycle.

Session three detailed the GMAP PDD schema development and content. The opening presentation in this session offered an overview of the IDEF methodology employed which involved model verification, and schema specification using EXPRESS. Also included was a scope comparison of GMAP to the current PDES work. The second part of this session consisted of descriptions of the GMAP PDD schema content.

The fourth session focused on the GMAP and PDDI extensions software. This presentation reviewed the original PDDI software components and explained the enhancements needed to support the GMAP interface architecture. These enhancements were then presented in more detail. They were: Schema Manager, N/VI, and System Translators.

At the end of the fourth session, the meeting was divided into two groups. The IRB members adjourned to an executive session with Pratt & Whitney and the USAF to discuss GMAP status and technical direction in more detail. The observers were provided an opportunity to join one of three round table discussions on the topics presented in sessions 2, 3, and 4.

Session five was devoted to presentations on the GMAP application interfaces and planned demonstrations. The first presentation in this session reviewed the contract commitment for demonstration, explained where in the life-cycle these demonstrations fell, and also outlined the GMAP PDD usage for each of the demonstrations. This was followed by a briefing on each of the planned demonstrations. The last presentation in this session reviewed the demonstrations being conducted on the PDDI extension contract.

The last technical session included a review of the PDDI extension project organization as well as the PDDI extension membership. The presentation focused on the efforts being devoted to PDES/Standard for the Exchange of Product Model Data (STEP) support, electronic definition, PDD modeler, and configuration support.

3.1.1.4.3.4 Fourth IRB Meeting

The fourth GMAP IRB meeting was held at the Holiday Inn near Bradley Airport in Connecticut 3 and 4 December 1987. Structured as a highly interactive workshop, the meeting dealt with the issues and concerns of the minimum requirements of a product modeler. Approximately 40 people were in attendance at this meeting which was restricted to IRB members and a few invited guests.

Introductory comments were given by Linda Phillips, Pratt & Whitney GMAP Program Integrator. Ms. Phillips welcomed everyone and reviewed the agenda for the workshop. She also presented a review of the status of the project and described the technical progress to date.

Mr. Richard Lopatka, Pratt & Whitney GMAP Program Manager, followed with welcoming remarks. Mr. Lopatka spoke of the motivators for this meeting. He stated that the general purpose of the meeting was to discuss the various issues regarding a product modeler. Next, Mr. Lopatka discussed the Technical Issues in Product Data Transfer. These issues fell into four major categories:

- Technology Shortfall
- Dynamic Environment
- Integrated Approach
- Special DoD Requirements.

A more in-depth discussion of these issues is presented in Appendix C. This presentation was well received by those in attendance and helped to set the tone for the remainder of the workshop.

Next, the IRB workshop Chairman, Mr. Edward Schumaker, reviewed the primary reasons for the workshop:

- Feedback from the last IRB meeting concerning the Minimum Requirements for a Product Modeler document

- PDDI and GMAP technology development efforts had shown the need for some sort of a Product Modeler to generate the necessary models

- That, in the future, PDES implementations will need some method of getting data into the product database.

Mr. Schumaker then reviewed the structure and breakout of the discussion groups, the questions for discussion, and assigned session leaders. Everyone in attendance was assigned to one of the groups.

The remainder of the meeting revolved around the session workshops and reports of the groups back to the total workshop. As a result of this meeting, the following action items resulted:

- At the next IRB Meeting, the GMAP team would present a summary of the discussion of this workshop. Also, plans for revising the Minimum Requirements of a Product Modeler would be required.

- Discussion of a Product Modeler and the Minimum Requirements Document would be included in the GMAP end of contract videos.

- Pratt & Whitney would compare the Product Modeler requirements to the Navy CAD/CAM specification.

The feedback from those in attendance indicated that the workshop was very successful.

3.1.1.4.3.5 Fifth IRB Meeting

The fifth IRB meeting was held on 1 and 2 March 1988, in St. Louis, Missouri. Seventy-eight people registered for the meeting.

The primary purpose of this meeting was to provide an end-of-contract debriefing on the PDDI extension program that ended December 1987. Videotapes of the PDDI extension demonstrations were shown on both days before and after formal presentations. The meeting also included an update on the GMAP program.

Ms. Linda Phillips opened the IRB meeting with a welcome and a review of the two day agenda. Chairman George Hess followed by congratulating the Air Force and MCAIR on the success of the PDDI program.

Mr. Gerald Shumaker, Area Manager of the Computer Integrated Manufacturing/Manufacturing Science at Wright Patterson Air Force Base, spoke next about the Materials Lab perspective on PDES.

The PDDI and PDDI extension programs were then reviewed. The objectives of PDDI program were to: functionally replace the engineering drawing, provide an interface between Engineering and Manufacturing, and demonstrate the transfer of PDD between dissimilar CAD/CAM systems. The PDDI extension program extended the PDDI schema to include electronic components, studied product modeler development, demonstrated a two-way interchange of two PDD models with a subcontractor, and developed a PDDI software configuration control system.

Also, an overview of the PDDI and GMAP digital exchange environment was provided by MCAIR. It focused on the exchange components used in this environment, the system architecture, and model creation.

A description of the PDD "modeler" developed at MCAIR was also presented. This "modeler" used graphics software to create, manipulate and interrogate working form models. The "modeler" used the geometry created in MCAIR's CAD/CAM system, model access software, and data dictionary entity definitions. A key requirement of the PDD modeler was that it perform with any entity that may be defined without having to modify the software for each entity addition or change. This was accomplished via the data dictionary. PDD models used for the demonstrations of the PDDI extension contract were a machined rib, composite rib, B1 spar clip, printed wiring assembly, and a printed wiring board.

Next, the demonstration of the digital exchange-customer demonstration with MCAIR and the Sacramento Air Logistics Center (SM-ALC) was reviewed. In this demonstration, models of a 3-axis machined rib and a composite rib, designed and built by MCAIR, were communicated to SM-ALC using the MAS and system translator. SM-ALC, in turn, utilized the system translator, the MAS, and a Unigraphics translator to place the models in the Unigraphics data base. SM-ALC then manufactured the 3-axis machined rib and sent it to MCAIR for inspection.

An overview of the digital exchange-subcontractor demonstration was also presented. Partners in this demonstration were MCAIR, LTV Aircraft Products Group, and Automation Technology Products (ATP). MCAIR designed and modeled a machined rib that was then

manufactured by LTV. LTV designed and modeled a B1 spar clip that, in turn, was manufactured by MCAIR. ATP developed the native system translator that imported and exported the 3 axis rib and the B1 spar clip models.

The PDDI electronic component phase of the PDDI extension program focused on broadening the PDDI schema to include printed wiring assemblies and printed wiring boards. Partners in this demonstration were McDonnell Douglas Astronautics (MDAC) and Westinghouse. This demonstration determined the data needed to define a printed wiring assembly and printed wiring board, expanded the PDDI conceptual schema to capture printed wiring assembly and printed wiring boards, defined a sample printed wiring board/assembly, created a working form model, and finally, compared existing and emerging neutral data formats for electronics with the PDDI schema.

The objectives of the PDDI software configuration control system (SCC) were to control and track the distribution of PDDI software to and from authorized development contractors and authorized PDDI users from central locations. The SCC is IBM-PC based and uses dBASEIII which is a relational database. A demonstration of the system was given after the presentation.

An IRB executive session was held to review the presentations given on the 1st day. The members were generally pleased with the results of the PDDI extension contract and strongly recommended that results of the project be thoroughly documented. They asked that the results of the 3 axis machined rib be documented so that others could benefit from MCAIR's experience.

Ms. Linda Phillips presented plans for the GMAP video tapes, including the IRB's review of the draft scripts for the videos. The IRB agreed to review a pre-release of the video scripts.

The second day of the meeting began with a review of the agenda by Ms. Phillips. A presentation of current PDES support by MCAIR and D. Appleton Company (DACOM) was given. MCAIR and Pratt & Whitney personnel supported information models for the PDES community. The PDDI exchange format led to the development of the PDES exchange file format. Similarly, the PDDI data specification language led to the development of EXPRESS. The IGES/PDES prototype translator, the EXPRESS language and the GMAP/PDDI schema manager were reviewed by MCAIR.

Pratt & Whitney discussed the relationship of the PDDI and PDDI extension programs to the GMAP project. A roadmap document describing and cataloging the deliverables of the three projects was distributed.

Plans for revising the "Minimum Requirements for a Product Modeler" document were also presented by Pratt & Whitney. The document would be renamed to "Functional Requirements of a Product Modeler". Pratt & Whitney planned to send out an RFP that would establish a team of experts from a variety of disciplines to rewrite the document.

3.1.1.4.3.6 Sixth IRB Meeting

The sixth IRB meeting was held 15 and 16 September at United Technologies Conference Facilities in Orlando, Florida. The primary objective of this meeting was to provide an executive review on the results and lessons learned in GMAP. Invited attendees included GMAP IRB members, Air Force GMAP Program Management personnel, and key members of the GMAP technical task groups. Approximately 40 people attended the meeting.

The meeting was divided into five sections. Session one featured the opening remarks and a brief overview of the GMAP objectives and current program status by Ms. Linda Phillips, Pratt & Whitney's GMAP Program Integrator.

Session two was devoted to viewing the GMAP demonstration videotapes. The session began with an overview of all the GMAP tapes and an explanation of the underlying objectives and audience at which the tapes were aimed. The first videotape shown was the Technical Summary. This tape was made by employing an interview style with key members of the GMAP technical team to provide a summary of the work accomplished on GMAP. The next two videotapes contained the life cycle demonstrations for the blade and disk. Prior to showing these videos, a brief introduction was given, one for the Blade and one for the Disk. A short discussion period followed each of the tapes. The fourth videotape consisted of demonstrations involving a plumbing attachment boss on an engine case. This demonstration was conducted to provide evidence that GMAP concepts can be applied to parts that are more typical of industries outside of aerospace.

The discussions that followed each of these tapes provided some excellent suggestions on how to make better use of the GMAP videotapes. A few suggestions were made on possible modifications to the tapes themselves.

During the second session, video personnel worked with selected members of the IRB to film interview segments for the executive overview tape. This tape was produced to provide a management perspective of the GMAP efforts and the future impact on industry. Session two also consisted of several round table groups that allowed attendees to view the videotapes a second time and enter into more in-depth discussion with GMAP personnel concerning results and lessons learned.

The third session presented an opportunity for Air Force representatives to voice their opinions of the GMAP work. Plaques of appreciation were given by the Air Force to the IRB members for their efforts. The Air Force also opened the floor for discussion concerning plans beyond GMAP. They also wanted to know the IRB's ideas on how GMAP could best be transitioned into industry and the Department of Defense (DoD).

The IRB expressed the opinion that the Air Force should sponsor the application of GMAP software to some of the parts that will be used in the Advanced Tactical Fighter (ATF). There should be some attention given to assemblies and assembly modeling. Interfaces to other databases should also be built. The feedback loop, and iterative design should also be examined along with the whole area of computer hardware and processing time, such as storage and the time needed to access part files. Configuration Management; what is released, to whom, when, and so on, is also important.

The fourth session focused on plans for the end-of-contract Industry Debriefing. The IRB members were questioned as to what audience should be captured, duration of the meeting, and what topics and degree of technical depth should the presented. Comments and suggestions expressed by the IRB were reviewed and incorporated as appropriate into plans for the Debriefing.

During the fifth session, GMAP personnel reviewed plans for the wind down of the contract and the 8 month extension that will permit the team to complete the supplier portion of the

Casting Tooling demonstration and the rewrite of the "Minimum Requirements for a Product Modeler" report. Also included in this extension will be a debriefing for the Repair Technology (REPTECH) organization and participation in CIM Industry Days.

3.1.1.5 Software Quality Assurance (SQA)

Pratt & Whitney prepared a preliminary Software Quality Assurance Plan to ensure that computer software developed during the program conforms to quality requirements in a cost effective manner. The Plan applied to all program software deliverable to the Air Force. The following paragraphs summarize its coverage.

3.1.1.5.1 Establishment of SQA Authority

Pratt & Whitney's authority for Information Systems to provide overall administration of SQA is defined in our Quality Manual. In addition, each subcontractor delivering GMAP software developed a SQA plan that adheres to the contents of the Plan.

3.1.1.5.2 Configuration Management

Procedures were developed to control configuration management and library controls. The personnel responsible for developing a specific subsystem were also responsible for controlling and maintaining the associated source libraries. They were also responsible for delivering the correct version of the source and object code to the subcontractor. The SQA organizations audited the controlled software libraries. Provisions for off-site storage, recovery procedures, and purging were also covered in this section of the document.

3.1.1.5.3 Program Documentation

Procedures governing program documentation were developed. Program notebooks or file folders contained the following components: introduction, requirements, detailed design, test criteria, and programming changes. Specification compliance and procedures relating to user guides were also included.

3.1.1.5.4 Corrective Action

Corrective action procedures were established to provide:

- Identification/documentation of software problems
- Analysis of problem causes
- Adequacy of problem resolution
- Authorization to implement the change
- validation/verification of the change implementation.

3.1.1.5.5 Testing

Procedures were developed to control testing of software. The SQA organizations monitored software testing. They also audited test documentation and reporting for completeness, adequacy, and conformance to requirements. Additionally, test support software were verified to comply to the program requirements established for that software.

3.1.1.5.6 Tools, Techniques, and Methodologies

Tools, techniques and methodologies used by the project were identified. Examples include: automated system to generate charts for use as a design tool; walkthroughs conducted to verify codes, etc.

3.1.1.5.7 Reviews and Audits

Although, Pratt & Whitney was responsible for coordinating the SQA program, all deliverable software under the GMAP contract was developed by MCAIR and ITI. Both of these contractors developed preliminary SQA plans supporting Pratt & Whitney's overall plan. Pratt & Whitney maintained copies of these plans and periodically audited contractor adherence to them.

Reviews and audits were conducted to determine the level of compliance to the SQA requirements. Subcontractors audited areas such as systems requirements review and systems specification review.

3.1.2 Identify Geometric Modeling Application Interface Needs (Subtask 1.2)

The IDEF0 functional modeling efforts resulted in approximately 100 candidate functional applications being identified for the IDEF1X information modeling methodology. These included:

- Graphic systems
- Geometry processors
- Numerical/control (N/C) toolpath utilities
- Cooling hole laser drilling programs
- Coordinate measuring machines program generators
- Finite element stress programs
- Tolerance chart programs.

3.1.2.1 Establish Information Needs

Criteria were established to aid the scoping of the numerous functional applications down to those to be modeled for information needs. Review and discussion of these criteria among experts from the functional areas, UTRC IDEF0 modelers, and other GMAP personnel led to the development of five basic questions.

1. How important is this application to the full life-cycle coverage of turbine blades and disks?

2. What is the breadth of the functional application in the full life-cycle coverage?

3. What is the depth of the functional application in terms of producing or consuming PDD?

4. If this application is supported, how much enhancement or advancement will be enabled?

5. Does the application meet the requirements of the GMAP contract?

As a result, the following 16 key functional application areas were selected for evaluation of information, or data, needs.

- Preliminary Engineering Design
- Detailed Blade and Disk Design and Analysis
- Final Blade and Disk Design and Analysis
- Detailed Engineering Specifications
- Casting Process Planning
- N/C Programming for Casting Molds and Dies
- Categorize and Review Parts/Processes
- General Process Planning
- Tool Design
- N/C Programming for Disk Machining
- N/C Programming for Laser Hole Drilling
- Quality Requirements Engineering
- Programming Automated Inspection Devices
- Provide Technical Support
- IBIS
- RFC.

Each area was investigated for mechanisms, both computerized and noncomputerized, that were creators or users of PDD. Collectively, the applications studied represented a comprehensive cross section of technical disciplines common to the design, manufacture, and support of complex mechanical products.

The first step in the investigation was to document the current environment, focusing on the functional interrelationships of the areas involved. This step established the as-is system.

Personnel in appropriate functional areas were interviewed to identify and collect source material, to understand the flow of PDD through the life cycle, and to determine user interface and data needs, and benefits. Next, this information was analyzed to determine the information needs of the functional areas investigated. In addition, information compiled allowed the investigators to establish opportunities for improvements to the overall systems. This step established the to-be system.

For descriptions of the application areas and discussions of the as-is and to-be conditions, readers may consult the GMAP Needs Analysis Document (NAD), CI NAD560240001U. The PDD needs for each of these areas are summarized below.

3.1.2.1.1 Preliminary Engineering Design

Investigation determined that there were no PDD-related needs this early in the design process. Most of the data at this point are considered product data because product shape has not yet been determined. Feedback capability of PDD, however, would be useful.

3.1.2.1.2 Detailed Blade and Disk Design and Analysis

Investigation identified these following PDD-related needs for this function.

- Internal geometry of ribs, trip strips, pedestals, and other internal cooling features, and all wall thicknesses were necessary.
- The ability to stack and fair both internal and external geometry, thus creating a 3-D airfoil shape, was needed.
- Storage of the complete blade and disk geometry in a form that accommodates original definitions and working representations of geometry was required.
- Three-dimensional, finite-element modeling was required, as was data storage, data management, and data security system to allow rapid communication of geometry and other related information.

3.1.2.1.3 Final Blade and Disk Design and Analysis

The following PDD-related needs were identified for this function.

- Airfoil external shape, airfoil internal feature definition, and the ability to create or extrapolate additional extended airfoil sections for manufacturing were required.
- The ability to integrate the preceding information into existing computer files was needed.
- The capability of building cooled airfoils electronically (including the ability to add, delete, and modify functional subsets of the model) was also needed.
- Cooling hole descriptions for shaped and circular holes were required.
- Tolerances associated to geometry were needed.
- Assembly information was needed.
- Pratt & Whitney specifications were necessary.
- Notes and administrative data were needed.

3.1.2.1.4 Detailed Engineering Specifications

The following PDD-related needs for this function were identified.

- The ability to represent the complete blade and disk geometric definition via mathematical description needed to be provided. Existing methods required illogical human interpretation (for example, "fair smoothly").

- The addition of tolerance and datum information (and nongeometric data such as notes, finish, and approvals) was required.

- The computer data base needed to correlate PDD with conventional drawing output to satisfy the human need for visualization of requirements.

- PDD needed to include "source data" to construct evaluated models, rather than be limited to the evaluated models alone.

3.1.2.1.5 Casting Process Planning

The following PDD-related needs for this function were identified.

- A complete and accurate 3-D model was needed to generate the wide variety of surfaces and geometric representations required to support finite-element casting simulations and the development of tooling requirements.

- Support of constructive reference geometry was needed to support dimensional adjustments.

- Intelligent support of gage points, datums, reference lines, and airfoil dimensioning and tolerancing systems was needed.

3.1.2.1.6 N/C Programming for Casting Molding and Dies

The following PDD-related needs for this function were identified.

- There was a need for an accurate 3-D model to represent geometry in its simplest, most complete form and to generate different surfaces and different mathematical surface representations.

- There was a need to standardize the mathematical representation of complex splined aerodynamic surfaces or to identify a compatible common denominator that could be shared and used between different systems. This would require the use of stable, generally usable cubic splines.

- Explicit definition of all geometry was needed.

- The ability to support reference data was needed. This included surface normals/tangents and definition of airfoil inner and outer contours below the root and beyond the tip.

- The ability to support constructive geometry in the model was needed.

- Also needed was the intelligent support of gage points, datums, reference lines, and airfoil dimensioning and tolerancing systems.

- There was a need for interactive graphics systems to support surface modifications and offsets associated with nonlinear casting and manufacturing factors such as ceramic shrinkage and EDM overburn.

3.1.2.1.7 Categorize and Review Parts/Processes

The following PDD-related need for this function was identified.

- Automatic GT code generation required a computer model that explicitly identified dimensions, tolerances, features, topological groups, materials, and process requirements such as shot peening and joining.

3.1.2.1.8 General Process Planning

The following PDD-related needs for this function were identified.

- A complete, integrated 3-D part model was required to support the computerized process planning environment.
- Constructive geometry was required by the GENCAPP system.
- Support of dimensions, tolerances, gage points, and datums was required for determining sequence of cuts and fixturing requirements. This included associative geometric tolerances.
- Intelligent support of notes was required to support planning for chemical and metallurgical processes such as coating, heat treat, and shot peening. This included surface finish and material properties.
- Features were a key to automating Process Planning because individual processes make features.
- Support of in-process part geometry and tooling geometry was required for Process Planning and for passing requirements to Tool Design and N/C Programming.

3.1.2.1.9 Tool Design

The following PDD-related needs for this function were identified.

- A complete, integrated 3-D PDD model with dimensions, tolerances, and gage points was needed.
- Accurate representation of all geometry, including airfoil geometry, was needed.
- The ability to support various geometric representations such as wireframe, surface, and constructive geometries, was needed.
- Feature identification was necessary.

- The ability to support complex airfoil surfaces and internal cooling passages was needed.

- The support of intermediate manufacturing and tooling geometries, was needed.

3.1.2.1.10 N/C Programming for Disk Machining

The following PDD-related needs for this function were identified.

- Complete, integrated 3-D geometric models that support final product, intermediate manufacturing part shapes, and tooling were needed.

- Multiple-part geometry representation capability was required to support different N/C applications. For example, 2-D profiles were required for turning, while 3-D models are required for machining.

- The ability to support features and patterns such as bolt hole patterns was needed. This would enable automatic generation of pocketing sequences, roughing and profiling sequences, and bolt-hole drilling sequences.

- Support of constructive geometry, datums and dimensions for situations such as radius runout and sharp edge dimensions were also needed to define geometry for N/C programming.

3.1.2.1.11 N/C Programming for Laser Hole Drilling

The following PDD-related needs for this function were identified.

- Laser hole drilling required definition of hole patterns using constructive geometry based on the use of datum planes and gage points.

- Interactive graphics programming required a 3-D part model.

3.1.2.1.12 Quality Requirements Engineering

The following PDD-related needs for this function were identified.

- Support of quality assurance data sheet information as part of process requirements was required.

- Types and sequences of inspections were required to be identified.

- References to specifications and standards related to specific features and processes needed to be supported.

- The ability to identify features, dimensions, tolerances, and inspection requirements as critical and major characteristics was needed.

3.1.2.1.13 Programming Automated Inspection Devices

The following PDD-related needs for this function were identified.

- A complete, 3-D electronic PDD model, which intelligently supports features, dimensions, tolerances, and notes, was needed.
- Notes must be supported intelligently to support airflow, nondestructive testing, and dimensional inspection requirements such as dishing.
- The use of traceability numbers was needed for nonserialized parts to support automated inspection applications, particularly airflow inspection. This allowed the data to be used for trending and engineering evaluation.
- The intelligent support of gage points, datums, and reference lines used by manufacturing and inspection was required.
- Airfoil dimensioning and tolerancing requirements such as stacking lines, airfoil sections, gage points, and features, was needed.
- Intermediate manufacturing geometries and processing requirements were also needed to support in-line inspection.

3.1.2.1.14 Provide Technical Support

The following PDD-related needs for this function were identified.

- A complete PDD model was needed by Product Support.
- Support of the tooling geometry was required in the design of the ground-support equipment.
- Accurate representation of all geometry was required.
- Various geometric representations, such as wireframes, surface, and constructive geometries, were needed.
- Required inspection and maintenance sequences needed to be identified.
- References to specifications and standards related to specific processes needed to be supported.

3.1.2.1.15 IBIS

The following PDD-related needs for this function were identified.

- A complete bi-cubic representation of the blade was needed.
- Product support information on the technical order (the blade areas and the serviceable/repairable limits for those areas) was also required.

3.1.2.1.16 RFC

The following PDD-related needs were determined for this function.

- A mechanism was needed to define information associated with a specific period in the life cycle of a part.
- A mechanism was needed to specify required administrative data, such as revision information and material type.
- 3-D geometry and topology capable of defining areas targeted for inspection were required.
- Mechanisms to specify a set of parameters that indicate the maximum serviceable and repairable limits of surface and internal flaws in various orientations were required.

3.1.2.2 Derive and Analyze GMAP Needs

The PDD needs for each of the 16 applications were converted into specific types of data that would be needed across a broad spectrum of industry. This resulted in six classes of data: Geometry, Topology, Form Features, Tolerances, Nonshape and Notes, and Administrative and Assembly. As a result of the IDEF1X process, a new data class, "Shape", was added. The Shape data class primarily integrates geometric and nongeometric data. The Topology data class became one of three subclasses of Shape. The Form Features data class was incorporated into the Shape subclasses.

The generic data needs of each class are tabulated on the following pages. For a more complete description, along with associated benefits of the data needed, refer to the Needs Analysis Document (CI NAD560240001U).

3.1.2.2.1 Geometry Data Needs

The Geometry data class represents shape information of complex mechanical parts concisely and unambiguously. This class supports the underlying geometry required for other classes such as topology, tolerances, features, shape, and nonshape data. The entities in this class support the geometry found in the life cycle activities of turbine blades and disks. Therefore, the complexity of these parts and of their life cycle gives GMAP a broad scope, but allows the implementation of GMAP schema to a wide variety of parts.

The GMAP approach to geometry is to include the smallest set of entities needed in support of life cycle activities, and to support geometry common to most CAD/CAM systems. Unlike the other classes, geometry is very hierarchical. There are multiple ways to represent the same thing, and these multiple representations are used throughout the life cycle of many parts, not only turbine blades. The intent is to eliminate any multiple or redundant definitions while maintaining precision and conciseness of representations.

The Geometry class contains points, vectors, matrices, curves, and surfaces. Geometric tolerancing is addressed to ensure data integrity. The ability to group geometric entities and to

name them is also included. This ability can be used in many ways: to supply a means of grouping some or all part cross sections, or to group geometry that defines part-specific features not represented as a form feature. Table 3-8 identifies the Geometry data needs.

TABLE 3-8.

GEOMETRY DATA NEEDS

Distinguish Between 2-D and 3-D Geometry
Bounded and Unbounded Geometry
Geometric Grouping
Minimum Number of Curve Representations
B-Splines, Polynomial Splines, Conic Curves
Minimal Set of Surface Representations

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3.1.2.2.2 Shape Data Needs

The Shape data class was created out of a need to represent intuitive elements of product shape. These elements show no regard for the particular geometric modeling method used to represent the part. This data class has three major subclasses: Shape Element, Shape Representation Elements, and Geometric Construction Elements. The Form Features data class was incorporated into these subclasses.

3.1.2.2.2.1 Shape Element

Shape Elements are used to represent intuitive aspects of part shape such as zones, surface area, faces, etc. This concept was later adopted by the PDES community. Table 3-9 lists the Shape Elements in the GMAP schema.

TABLE 3-9.

SHAPE ELEMENT DATA NEEDS

Vertex
Edge
Surface Area
Zone
Subface
Face
Form Feature
Object
Simple Object
Compound Object
Feature of Size
Constructed Geometry

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Form features data represented a significant portion of the Shape Element subclass of Shape Data needs. Form features data were needed to identify and describe geometric design and

processing units of a part. This is because a great deal of industrial understanding and expression is in terms of form features, and unit processes typically produce recognizable form features. Table 3-10 lists the Form Features data needs.

TABLE 3-10.

FORM FEATURE DATA NEEDS

Form Feature Representation
Alternate/Multiple Feature Representations
Representations of Features in Different Geometric Models
Generic Feature Modeling Capabilities
Feature Modeling Growth Directions
Constructive Feature Representations
Primitive Constructive Feature Representations
Edge Modifier Features
Sweep Representations of Features
Section-defined Features
Replicate Feature Representations
Feature Patterns
Nonconstructive Feature Representations
Compound Feature Representations
Feature Component Location
Feature Function
Feature Limits

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3.1.2.2.2.2 Geometric Construction

This Geometric Construction subclass of the Shape data class provides the capability to construct geometric entities not necessarily on the part. The data needs of this subclass were derived from the needs of other data classes. The definition of these needs was driven primarily by the requirement to tolerance off-part geometry.

3.1.2.2.2.3 Shape Representation (Topology)

The Topology data class was changed to the Shape Representation subset of the Shape data class. Shape Representation data structures geometric information into a complete, unambiguous representation of nominal part shape. Shape Representation relates geometric data, establishing connections and bounds.

The PDDI and GMAP walkthroughs identified four types of solid models used by applications in representing the GMAP parts: flat pattern or linear extrusion representations, bodies of revolution, laminate representations, and 3-D boundary representations. [Several other useful solid model types could be added to this list: half spaces, constructive solid geometry, 3-D sheets, locally 2-1/2-D (linear and rotational sweeps), and different types of spatial decomposition models such as octrees.]

For GMAP, Shape Representation data consist of the information necessary to structure geometric information into solid models of the four types identified in the PDDI and GMAP part walkthroughs. Table 3-11 lists the Shape Representation data needs.

TABLE 3-11.

SHAPE REPRESENTATION DATA NEEDS

Boundary Representations
Body of Revolution Representations
Flat Pattern (Extrusion) Representations
Laminate Representations

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3.1.2.2.3 Tolerance Data Needs

Tolerance data provide entities that satisfy the need to express the allowable variation of products. This data class, originally identified in the PDDI project, provides a means to control dimensional relationships and physical characteristics of the product.

Dimensioning and tolerancing is fundamental to stating engineering design requirements for the manufacture, assembly, and support of jet engine components and is most commonly conveyed on engineering drawings of one form or another. Variations of tolerancing involve company-specific dimensioning and tolerancing conventions, the use of notes (text) to state or further qualify tolerancing requirements, the use of engine operating cycle-dependent tolerances in logistics, and the use of nondimensional tolerances such as airflow limits. These forms needed to be systematized.

Tolerance needs addressed in the Tolerance data class are concerned with the meaning underlying the application of tolerances to a geometric model, not the graphical annotation of the same. Graphical manifestation of tolerances on an engineering drawing is an application that might be enabled by the complete product definition model. Table 3-12 lists the Tolerance data needs.

TABLE 3-12.

TOLERANCE DATA NEEDS

Tolerancing of Intrinsic Features
Tolerancing of Extrinsic Feature Relationships
Combined Individual Feature and Relationship Tolerancing
Tolerances Associated with On-part Dimensions
Tolerances Associated with Off-part Dimensions
Feature Size Tolerancing
Location Tolerancing
Form Tolerances
Datums
Projected Tolerance Zones
Tolerance Function
Material Condition Modifier
Statistical Process Control Tolerances
Airflow Tolerances

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3.1.2.2.4 Nonshape and Notes Data Needs

Nonshape data represents and supports PDD communicated in a textual manner. This data class includes information typically defined by alphanumeric text in the form of notes and instructions. A diversity of textual data are required along with the product shape definition to completely define the design intent of a product. Though the shape of a product is informative, an explanation of that "picture" is almost always required. Furthermore, the design intent includes information that is simply not graphically representable.

The nonshape data supports drawing notes that depict a "who, what when, where, and how" concept. The "who" may be a statement about which discipline area is to be responsible for the nonshape requirement, such as inspection, processing, or assembly. The "what" is the specific statement of a requirement for the "where', such as "heat treat product" or "protective coat this area". "When" embodies any concept of sequencing or precedence, usually represented by "before" and "after" statements. The "where" can be a description or indication of where on the product the "what" is to be applied. It can be the entire product, a certain area of the product, or certain areas of the product to be excluded. The "how" is generally a reference to a specification or a procedure to be followed in producing the desired result. It could also be explicit instructions included on the drawing itself. Table 3-13 presents the Nonshape data needs.

TABLE 3-13.

NONSHAPE DATA NEEDS

Discipline Identification
Computer-sensible Information
Nonshape Text
Cross-references
Information Priority
Information Sequence
Nonshape Processing Information
Treatment Information
Inspection Information
Assembly Information
General Information
Specification References
Material References
Derived Data

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3.1.2.2.5 Administrative and Assembly Data Needs

Administrative and Assembly data exist in several forms and with many purposes. Administrative data are usually used to manage an enterprise. Scheduling, planning, financial information, and certain technical data such as data exchange, product history and documentation, and engineering change control are examples of Administrative data.

An assembly is a type of product that consists of two or more product components. The product components are joined in some manner to produce the assembled product. Specific requirements and processes apply to the assembled product as a whole.

Assembly data convey the information necessary to perform the function or process by which product components are assembled to create a product. These data include administrative, shape, geometry, tolerance, and nonshape information. Many of these requirements are not unique to assembly products; however, the needs specific to assemblies were identified during GMAP walkthroughs.

Critical product information about the product components must be preserved in the assembly product. Relationships between the product components are established in the assembly. The product component properties and their relevant information (shape, nonshape, and so on) must be preserved. GMAP addressed the first-level assembly of blades and disks. Those data needs are presented in Table 3-14.

TABLE 3-14.

ADMINISTRATIVE AND ASSEMBLY DATA NEEDS

Product
Product Version
Product Component
Association of Product Version and Property
Association of Product Component and Property
Approval
Revision
Product Component Orientation
Tolerances
Zones in Contact
Nonshape Information for Assemblies

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3.1.2.3 Review Needs Analysis

A thorough discussion of the identification and prioritization of the GMAP data needs was documented in the Needs Analysis Document. However, key findings relating to these needs are summarized below.

- For complex mechanical components PDD must include all concepts, attributes, and relationships normally communicated from design throughout the product life cycle. The engineering drawing and related technical documents have been the vehicles historically used for this purpose. For complex mechanical components, both shape and nonshape information and process requirements are needed to fully represent a component (or assembly).

- Applications that are users of PDD, as opposed to those that are producers of PDD, are the primary beneficiaries of an electronic equivalent of the engineering drawing.

- Computer-sensible product data are needed for applications to become more automated. This is especially true for most applications studied in manufacturing, inspection and logistics support.

- The primary responsibility for creating PDD lies within the traditional mechanical design and drafting functions.

- Modelers need to be developed to create the required PDD. These modelers may actually be a system of modelers capable of providing the various shape and nonshape data required. For shape data, existing geometric and solid modelers are capable of producing the geometry and topology definitions required by some using applications, but not without problems and limitations.

- "In-process geometry" must be derivable and representable from PDD for Process Planning, N/C Machining, Automated Inspection, and Tool Design Applications.

- There is a need to preserve the constructive origins of shape PDD for some applications.

- Although solid model representation of shape is required for certain automated applications, not all applications require such complete information. Some applications only require 2-D geometry. Examples are applications dealing with Body of Revolution (BOR), or turned, parts and flat sheet-like parts.

- There is a need to represent geometry in multiple forms depending upon the using application. This leads to the requirement for standardized representations. Evaluator utilities capable of converting between standard forms would be very useful.

- Features are a key to applications such as automated process planning, since individual processes make features.

- Tolerances, datums, and their relationships to part shape are fundamental to future automated applications. Representations of tolerances and datums must parallel traditional industry standards for reasons of acceptability, useability, traditional practice, and so on.

- Process requirements normally conveyed to manufacturing and inspection via notes and specification invocation on engineering drawings must continue to be conveyed in the electronic PDD form. The bulk of of this information needs to be represented in a computer-sensible form. Other information is only human understandable and needs to be conveyed via note text in the PDD model.

- The information communicated from engineering and product support to logistics support is done so using the technical order. This information is analogous in form to the process requirements communicated from engineering to manufacturing. Provisions for incorporating these data in the full PDD model are essential.

- Administrative information pertaining to the control and management of the PDD needs to be included with the technical PDD.

- Assembly PDD is normally conveyed using layout and assembly drawings. Information contained on these traditional documents falls into categories similar to those required for component PDD. These are geometry, topology, features, tolerances, nonshape and notes (process requirements being assembly requirements in this case), and administrative.

3.1.3 Define System Requirements (Subtask 1.3)

3.1.3.1 Establish GMAP Requirements

Identifying the data needs led to the establishment of the PDD requirements of the GMAP system. These requirements were synthesized from the results of the needs analysis and are presented in the form of entities mapped to the needs expressed in the NAD as well as specific requirements to support RFC and IBIS.

3.1.3.1.1 PDD Requirements

Tables 3-15 through 3-21 below summarize the entities required to be represented for each data class.

TABLE 3-15.

GEOMETRY DATA ENTITY REQUIREMENTS

Base Surface	2-D Circlular Arc
B-Spline Surface	2-D Closed Curve
Cone	2-D Conic Arc
Constructive Surface	2-D Coordinate
CRV STR2 Profile	2-D Curve
CRV STR3 Profile	2-D Curve Segment
Curve2 Profile	2-D Curve Segment Curve String Element
Curve3 Profile	2-D Curve String
Cylinder	2-D Curve String Element
Def Coord2	2-D Ellipse
Def Coord3	2-D Geometric Element
Def Point2	2-D Line
Def Point3	2-D Matrix
DEF PT2	2-D Open Curve
DEF PT3	2-D Open Curve String Element
Extrusion	2-D Point
Geometric Element	2-D Polynomial Spline
Irregular Curve Segment2	2-D Quasi Geometry
Irregular Curve Segment3	2-D Vector
Offset Surface	3-D B-Spline
Plane	3-D Circle
Point3 Boundary Curve	3-D Circular Arc
Profile	3-D Closed Curve
Profile 2-D	3-D Conic Arc
Profile 3-D	3-D Coordinate
RB Control COORD2	3-D Curve
RB Control COORD3	3-D Curve Segment
RB Control Point2	3-D Curve Segment Curve String Element
RB Control Point3	3-D Curve String
RB-Spline2 Control Point	3-D Curve String Element
RB-Spline3 Control Point	3-D Ellipse
Regular Curve Segment2	3-D Geometric Element
Regular Curve Segment3	3-D Line
Ruled Surface	3-D Matrix
Sphere	3-D Open Curve
Surface	3-D Open Curve String Element
Surface of Revolution	3-D Point
Trimmed Surface	3-D Polynomial Spline
2-D B-Spline	3-D Quasi Geometry
2-D Circle	3-D Vector

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TABLE 3-16.

SHAPE ELEMENT DATA ENTITY REQUIREMENTS

- Shape Element
- Vertex
- Edge
- Surface Area
- Form Feature
  - Feature Rep.
    - Explicit Feature Rep.
    - Constructive Feature Rep.
      - Primitive
        - Driven Feature
        - Rotational Feature
        - Section Defined Feature
        - Edge Modifier
          - Chamfer
          - Edge Round
          - Relief
        - Scallop
        - Rectangular Thru Slot
        - Edge Round
        - Primitive Feature Bound
        - Implicit Modifier Edge
        - Thread
        - Replicate Feature
        - Replicate Feature Omission
        - Compound Constructive Feature
        - Circular Feature Pattern
        - Circular Feature Omission
        - Rectangular Feature Pattern
        - Rectangular Feature Omission
      - Primitive Constructive Feature
        - BOR Groove
        - 3-D Rotational Groove
        - 3-D Blind Hole
        - BOR Blind Hole
        - BOR Thru Hole
        - Flat Pattern Hole
        - BREP Crimp
        - BREP Cutout Flange
        - 3-D Bend
        - 3-D Rectangular Pocket
        - Flat Pattern Rectangular Cutout
        - 2-D Phantom Edge
        - 3-D Phantom Edge
        - Flat Pattern Bend
        - Flat Pattern Bend Point

TABLE 3-16.

(CONTINUED)

Face
Subface
Zone
Object
Simple Object
Compound Object
Feature of Size
Constructed Geometry
Geometric Relation
Zone Component

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TABLE 3-17.

GEOMETRIC CONSTRUCTION DATA ENTITY REQUIREMENTS

Construction Geometry
Geometric Relation
Geometric Relation Reference

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TABLE 3-18.

SHAPE REPRESENTATION DATA ENTITY REQUIREMENTS

BOR Edge
BOR Face
BOR Object
BOR Rep Element
BOR Shell
BOR Subface
BREP Edge
BREP Element
BREP Face
BREP Loop
BREP Object
BREP Shell
BREP Subface
BREP Vertex
Flat Pattern
Flat Pattern Extruded Edge
Flat Pattern Extruded Face
Flat Pattern Extruded Subface
Flat Pattern Front/Back Face
Flat Pattern Front/Back Subface
Flat Pattern Loop
Flat Pattern Object
Flat Pattern Rep Element
Flat Pattern Segment
Flat Pattern Segment Intersection
Flat Pattern Vertex
Laminate Object
Laminate Rep Element
Located Ply Detail
Ply
Ply Detail
Ply Stack

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TABLE 3-19.

TOLERANCE DATA ENTITY REQUIREMENTS

Angular Location	Profile of a Surface
Angular Size	Profile Tolerance
Angularity	Projected Tolerance Zone
Circular Runout	Rectilinear Location
Compound Datum	Rectilinear Size
Concentricity	Related Coordinate
Coordinate Tolerance	Related Geometric
Curve Length	Related Line Profile
Cylindricity	Related Mismatch
Datum	Related Surface Profile
Datum Material Condition	Roundness
Datum Reference	Secondary Datum Reference
Datum Reference Frame	Simple Datum
Datum Target	Single-Sided Coordinate
Disposed Coordinate	Size Tolerance Qualifier
Flatness	Straightness
Geometric Tolerance	Tertiary Datum Reference
Individual Coordinate	Three Datum Reference
Individual Geometric	Frame
Individual Line Profile	Tolerance
Individual Mismatch	Tolerance Material Condition
Individual Surface Profile	Tolerance Property
Material Condition	Tolerance Qualifier
Mismatch	Tolerance Zone Indicator
One Datum Reference Frame	Toleranced Shane
Parallelism	Total Runout
Perpendicularity	True Position
Primary Datum Reference	Two Datum Reference
Profile of a Line	Frame

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INTERNAL FLAW CRITERIA
SURFACE FLAW PROXIMITY
SURFACE FLAW LIMIT
SURFACE REPAIRABLE FLAW LIMIT
SURFACE SERVICEABLE FLAW LIMIT
SURFACE FLAW DATA
SURFACE FLAW WIDTH
SURFACE FLAW DEPTH
SURFACE FLAW PROXIMITY.

3.1.3.1.2.2 RFC

Specific requirements identified to support the RFC system are summarized below.

- Procedures and programs were required to access, and show values of entities needed in the RFC interface.

- The following entities were required to convey the 3-D geometry and topology of areas on the part targeted for inspection:

  3-D GEOMETRIC ELEMENT
  ZONE COMPONENT
  SURFACE AREA
  FACE
  SUBFACE
  ZONE
  FORM FEATURE

- The following entities were required to define a specific period in the life cycle of a part to establish which inspection limits apply:

  CYCLE
  CYCLE-ZONE FLAW CRITERIA.

- The following entities were required to indicate maximum serviceable and repairable limits for various flaw configurations:

  FLAW CRITERIA
  SURFACE FLAW CRITERIA
  INTERNAL FLAW CRITERIA
  FLAW ORIENTATION
  FLAW CRITERIA ZONE
  ZONE FLAW CRITERIA
  CYCLE ZONE FLAW CRITERIA
  SURFACE FLAW DATA
  SURFACE WIDTH
  SURFACE DEPTH
  SURFACE FLAW PROXIMITY
  FLAW LIMIT

INTERNAL FLAW LIMIT
  INTERNAL REPAIRABLE FLAW LIMIT
  INTERNAL SERVICEABLE FLAW LIMIT
SURFACE FLAW LIMIT
  SURFACE REPAIRABLE FLAW LIMIT
  SURFACE SERVICEABLE FLAW LIMIT.

- The following entities were required to convey revision information, part identification, and material type:

PRODUCT
VERSION
REVISION
SPECIFICATION
MATERIAL
NONSHAPE REFERENCE
  MATERIAL SPECIFICATION REFERENCE
  MATERIAL NONSHAPE ELEMENT REFERENCE
  NONSHAPE ELEMENT PROPERTY REFERENCE
NONSHAPE ELEMENT
  TREATMENT
    HEAT TREAT
  MISCELLANEOUS
    TENSILE REQUIREMENTS

3.1.3.2 Establish Minimum Requirements of a Geometric Modeling System

A significant portion of the requirements definition included establishing the minimum requirements of a product modeler. Such a modeler was required to take advantage of the complete PDD capabilities provided by GMAP. This modeler would provide the capability to create, manipulate, and manage the full spectrum of such data — a capability not found in any existing system.

The results of this product modeler work were reported in Appendix D of the System Requirements Document (CI SRD560240001U). Discussions at the fourth IRB meeting indicated that their were five opportunities to enhance this report:

- The scope of stored PDD should be discussed.
- The management of PDD, as well as the administrative data, needs to be explored and proposed in the document.
- Requirements for interfaces to such things as applications, databases, and other systems should be discussed.
- The architecture of the data generation modules should be laid out for the reader to better understand what is being explained in the document.
- A number of additional areas should have been considered for discussion, and others more fully discussed.

As a result, Pratt & Whitney contracted D. Appleton Company (DACOM) to produce a follow-on document entitled "Functional Requirements of a Product Modeler" that addressed these issues. That document will be published as CI TTD560240003U.

3.1.3.3 Perform State-of-the-Art Survey

A survey was conducted to identify current and emerging technologies that impact the content, usage, exchange, and management of PDD models. This survey also identified technology voids by correlating the prioritized needs from the GMAP Needs Analysis Document with the survey findings.

The survey was conducted through the combined use of questionnaires and on-site interviews with both users and developers of CAE/CAD/CAM systems. Initially, questionnaires were mailed to the survey candidates and the responses were evaluated and documented. The next step was to use on-site and telephone interviews to gain a more specific understanding of key issues and to help correlate the survey findings with the data class needs.

The survey explored a variety of CAE/CAD/CAM modeling systems and applications of those systems. The survey investigated the types of data exchanged between product modeling systems today, as well as the data and information desired, but not currently being exchanged.

Both existing and emerging technological capabilities were surveyed to forecast new developments which may contribute to the GMAP project. Technology trends that potentially impact the manner in which data are created, stored, controlled, managed, and communicated were stressed.

Two different questionnaires were developed for the survey. The first was intended for developers of technology pursuant to GMAP needs. The second was for users of modeling software and applications impacted by GMAP. Questionnaires were mailed to approximately 100 survey candidates. Telephone follow-up was made with the individuals being surveyed to maximize the level of participation. The survey responses were evaluated to refine the on-site interview questions and candidate lists, and the results were documented.

Survey candidates were selected that best met the objectives of the survey, including:

- GMAP team members
- Turbine blade and disk suppliers
- CAE/CAD/CAM system vendors
- Major users of CAE/CAD/CAM systems.

The results of the survey were presented in the State-of-the-Art Document (CI SAD5602240001U), dated 27 March 1987, in four categories:

- **Available Technologies** — Examined user needs and current technology for relevant technologies

- **Needed Technologies** — Identified technologies that are needed to advance the state of the art

- **Technology Trends** — Described technology trends that several manufacturers and software developers are following

- **Correlation With Needs Analysis** — Focused on the availability of modeling and application software systems for creating and using each of the data classes identified in the needs analysis.

In summary, it was found that completely integrated product modelers are not yet available. Most of the modeling being done by system users was done to satisfy a particular application. For instance, two-dimensional views of an object were modeled for use in drafting. Three-dimensional wireframes and surfaces were created to represent a particular area on a part to be used for developing an N/C tool path definition. A rough (nondetailed) solid representation of the part was modeled for calculation of volume or moment of inertia. Manufacturing features were identified and stored for group technology or process planning.

The variety of computer applications was increasing throughout manufacturing enterprises. Software systems to support design and analysis, manufacturing, quality, product support, and logistics support functions have been implemented by SOA survey participants. The proliferation of applications in such diverse areas was placing great demands on both the quality and quantity of available PDD.

Most of the users surveyed were in the process of linking together their "islands of automation" with some type of application interface software. One portion of this linking process dealt with applications that require PDD in some format. Many different ways were being used to accomplish this, ranging from direct translators to system-wide common neutral files.

Management of digital drawings was based on native system file management capabilities and existing procedures for release and control of paper drawings. However, several system developers had announced software products developed specifically for management of computerized product data.

3.1.3.4 Review Requirements Definition

A thorough discussion of the efforts described above in Section 3.1.3 were documented in the System Requirements Document (SRD560240001U).

The main body of the System Requirements Document was separated into three major sections. The first section identified PDD requirements mapped to the data needs identified in Section 3.5 of the Needs Analysis Document. These requirements are stated in the form of bulleted lists, along with supporting rationale, to provide an understanding of the requirements, and to indicate how they were derived from the needs.

The second section of the System Requirements Document identifies enhancements to the PDDI software required to support exchange system needs identified during both the PDDI and the GMAP walkthroughs. Recommendations were included where requirements would be important for future consideration but fall beyond the scope of GMAP. Schema manager, access software, and translator requirements are identified. Needs were derived from both the GMAP Needs Analysis Document and the PDDI System Requirements Document (SRD560130000).

The last section of the System Requirements Document defines application requirements from a generic viewpoint and from the viewpoints of the IBIS and RFC systems. An important objective of GMAP was to demonstrate the use of PDD by communicating and manipulating PDD to support applications throughout the life cycle of turbine blades and disks. During the investigation of the GMAP needs, the existing flow of product information was examined and areas that would benefit from improved data flow and exchange were identified. The applications studied spanned the entire life cycle from conceptual design through logistics support.

3.2 Task 2 — Establish Preliminary and Detailed Design

Task 2 consisted of four subtasks:

2.1 Establish Preliminary Design
2.2 Review Preliminary Design
2.3 Establish Detail Design
2.4 Perform Critical Design Review.

In Subtask 2.1, a preliminary, or conceptual, design for GMAP was developed, including identification of required enhancements to PDDI technology and a plan for testing the GMAP system software. In subtask 2.2, this work was reviewed to ensure that the design met all of the system requirements established in Task 1. Subtask 2.3 detailed the design, and established plans for testing logistic application interfaces. Subtask 2.4 ensured review of the detail design.

3.2.1 Establish Preliminary Design (Subtask 2.1)

To establish a preliminary design, IDEF1X information modeling was performed for each data class. Overview diagrams of the information models were produced for communication and review. The content and capability of each data class were presented to an open audience of knowledgeable reviewers for comment.

The IDEF1X information model was verified and refined using a commercial computer software product. After verification of the IDEF1X information model, the lexical form of the conceptual schema in the EXPRESS language was produced. The lexical schema specification accompanied the graphic schema specification that was documented in the GMAP System Specification and related documents. Those documents are summarized below. Their relationship is depicted in Figure 3-21.

Volume II described the exchange file format, which is the PDES file format. Volume III provided an IDEF1X Readers Guide and the GMAP IDEF1X Information Model. The information model was presented in page-pair format with a subject entity diagram and an accompanying entity definition page. Volume IV consisted of an EXPRESS language specification and the GMAP EXPRESS Abstract Schema specification with illustrations and definitions.

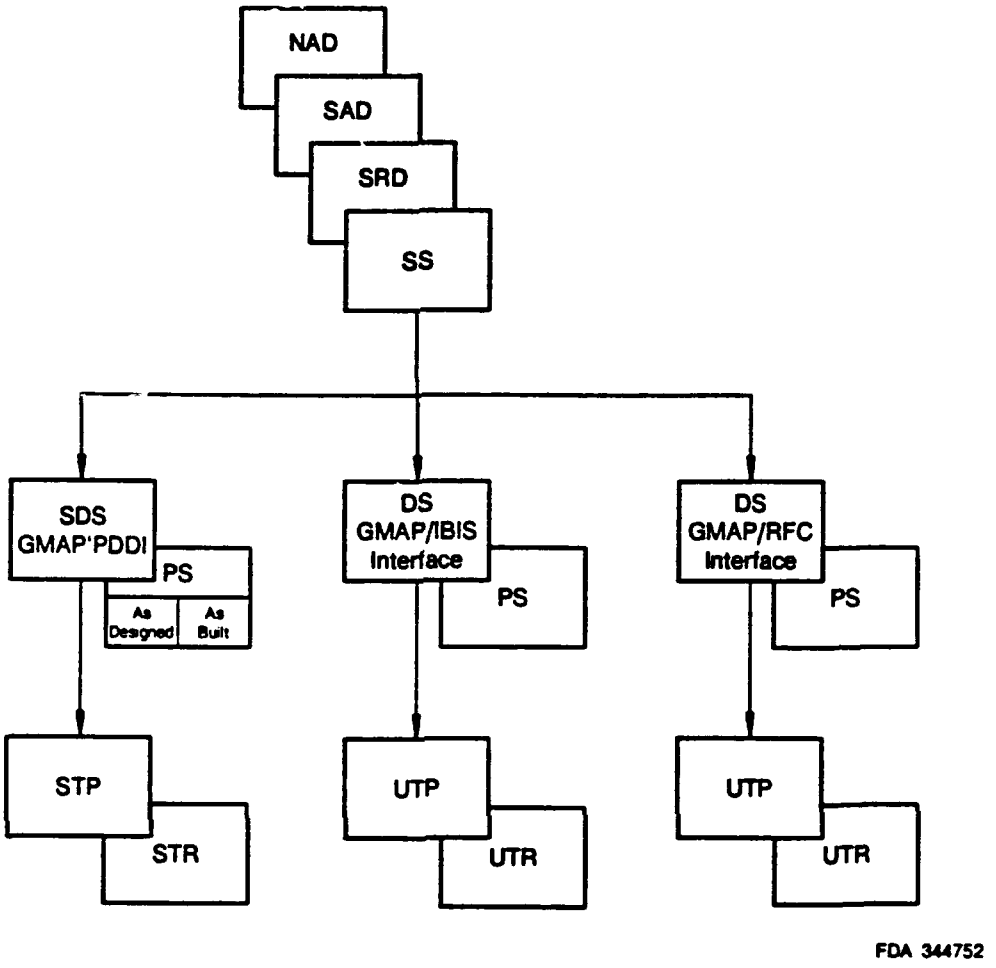

Figure 3-21. Interrelationship of GMAP Documents

The majority of the System Specification documented the GMAP schema. The schema was developed over a period of time during the walkthrough of the turbine blades and disks life cycle.

3.2.1.1 Produce System Specification

The GMAP System Specification (SS) (CI SS560240001U) consisted of four volumes. Volume I described four major components of the GMAP system:

- Conceptual Schema
- Schema Manager
- Model Access Software with N/VI
- System Translator.

As described under Task 1, investigations and interviews were conducted throughout the disciplines involved in the life cycle of these products. An IDEF0 function model was created

from the information gathered. The objective of the IDEF0 function model was to identify the functional applications involved in the blade and disk life-cycle. The functional applications identified were subjected to further scoping and a final set of functional applications was chosen.

The selected functional applications were then used as targets in the IDEF1X Information Modeling Methodology. This methodology was applied to the applications, and the data captured included the entities, attributes, and relationships involved. The IDEF1X diagrams were manually prepared and then verified for accuracy by using the JANUS software product marketed by DACOM. The validated, corrected model was then documented in Volume III of the GMAP System Specification. The diagrams were produced by an IDEF1X diagramming program prepared by UTRC. The validated entity and attribute names, and the relationship text were transferred from the JANUS work.

The JANUS work also created a structured modeling language output. This lexical form of the information model was used as input to a prototype translator to create an initial EXPRESS language version. That EXPRESS translation was manually conditioned into an appropriate GMAP Abstract Schema and published in Volume IV of the GMAP System Specification.

3.2.1.2 Produce System Design Specification

The System Design Specification (CI SDS560240001U) transformed the requirements stated in the GMAP System Specification into a conceptual design to build the system. Primarily, the System Design Specification consisted of information on: the Schema Manager, the MAS with N/VI, and the System Translator; the GMAP-to-IBIS Interface; and the GMAP-to-RFC Interface.

The main body of the System Design Specification discussed ten major areas of interest on these configuration items. These included:

- System definitions
- System characteristics
- Data characteristics
- Application interfaces
- Design and construction standards
- Information regarding GMAP system documentation
- Facilities and equipment
- Training and system installation.

The System Design Specification contained a detailed definition of the GMAP system components and the application interfaces developed at Pratt & Whitney. The RFC and IBIS application interfaces were documented in the two Development Specifications, CI DS560240011U and CI DS560240021U, respectively.

3.2.1.3 Produce System Test Plan

The System Test Plan (CI STP560240001U) provided a strategy for testing and validating the elements and functionality of GMAP. The elements of GMAP were the system components as defined in the System Design Specification. Plans called for the functionality of the system components to be validated through application demonstrations. The paragraphs below describe these plans in more detail.

The GMAP software components were to be tested in several phases. The first phase was individual Component Development Testing performed as the component programs were developed and enhanced. The second phase was Software Program Testing. Acceptance testing was the third phase. The fourth phase was System Integration Testing/Demonstrations in which the GMAP software was used in various CAD/CAM/CAE application demonstrations. These phases are described below. All development and testing was to be done in accordance with Pratt & Whitney's GMAP Software Quality Assurance plan (FR 19199-5) and MCAIR's GMAP Software Quality Assurance plan.

Phase 1 — Component Development Testing. Individual component test plans were developed in accordance with Institute of Electrical and Electronic Engineers (IEEE) software test documentation standards and are presented in the appendices of the System Test Plan.

Phase 2 — Software Program Testing was planned for two basic versions: a "Prototype" version and a "Test" version.

The "Prototype" version was pseudo-stable software developed for testing, training, and familiarization purposes. This software used data and models derived from the GMAP Conceptual Schema. This prototype version consisted of the MAS with the N/VI, and the System Translator incorporating the PDES file structure and the data dictionary.

The "Test" version was developed for general testing of the GMAP enhanced PDDI software and for building interfaces to demonstration applications. This test version consisted of the MAS from the prototype version, an enhanced System Translator, the N/VI, and the Schema Manager.

Phase 3 — Acceptance Testing for the test version included plans for using a sample model developed from the GMAP schema using the following concepts. The sample model contained entities made up of all possible combinations of primitives. These primitives were: integers and real numbers, characters, logicals, scalars, pointers, and arrays. The use of existing entity types in the testing ensured that any entity created would translate correctly. All software was tested using this acceptance model.

The Acceptance Test scenario is shown in Figure 3-22. This Acceptance Test simulated the processing of data through the GMAP system. The Schema Manager was used to convert the Conceptual Schema to physical schema (PASCAL include files or data dictionary files). These physical schema files were used to create part models which were translated to and from exchange format files.

Phase 4 — System Integration Testing/Demonstrations. A basic strategy for testing the GMAP components was to demonstrate the functionality of the GMAP system. In this phase, complete PDD would be defined and transferred to show the transportability of the software and the PDD. Several demonstrations, summarized below, were planned to show the integration of the GMAP software with various application software.

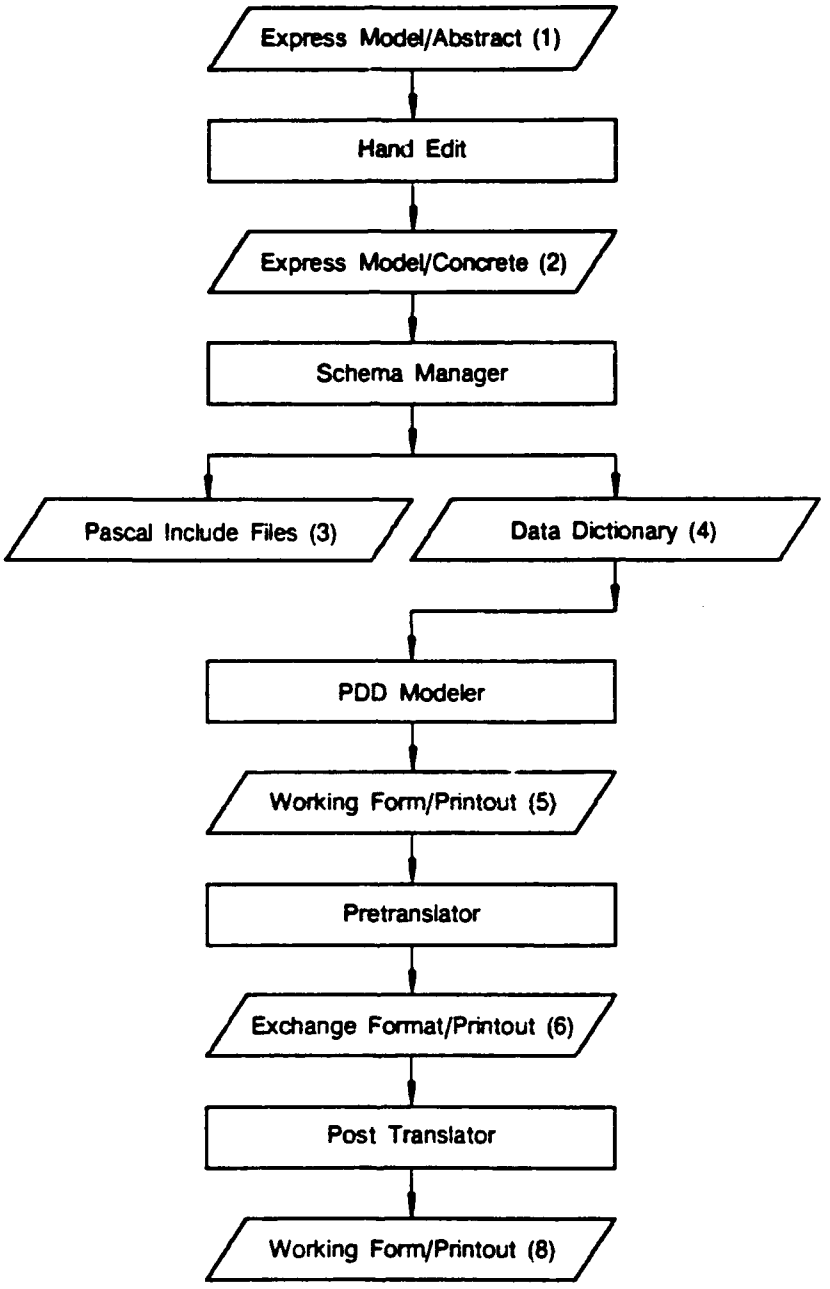

Figure 3-22. Acceptance Test Scenario and Criteria

Candidate applications were identified during the IDEF0 functional walkthroughs and revisited during test planning. Figure 3-23 contains a matrix of the final applications, indicating life-cycle area and part class. A high level breakdown of the GMAP PDD usage for each of these test applications by data class is presented in Table 3-22.

Blade	Parametric Blade Design	Casting Tooling	IBIS
Disk	Disk Design	PROCAP Feature Based N/C and CMM Programming Disk Forging	RFC
Other		Case Boss Inspection Case Boss N/C PDDI Parts	

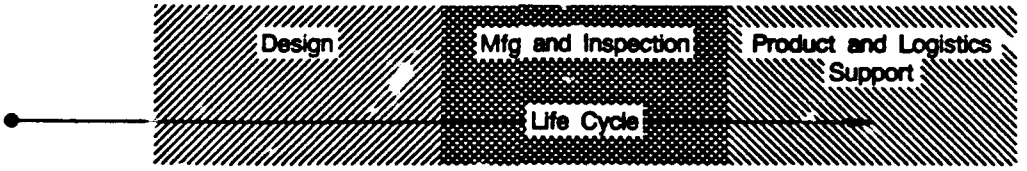

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Figure 3-23. Matrix of GMAP Demonstrations

3.2.1.3.1 Parametric Cooled Turbine Blade Design

This application would demonstrate how the elements of the solid part are integrated in a complete model and show that rapid changes are possible with minimum rework. The model created in this application was represented in GMAP PDD form and supported downstream demonstration applications.

3.2.1.3.2 Casting Tooling Applications

The casting tooling application would be a comprehensive demonstration of the use of GMAP in supporting the manufacture and inspection of turbine blades. There were four major elements of this demonstration planned:

- Pratt & Whitney Internal Numerical Control (N/C) Electrode Machining
- Supplier N/C Electrode Machining
- Coordinate Measuring Machine (CMM) Inspection
- Automated Optical Inspection.

3.2.1.3.3 Integrated Blade Inspection System (IBIS)

IBIS is the automated blade inspection system for the San Antonio-Air Logistics Center (SA-ALC) logistics support facility. More information on this application can be found in Task 3, Integrate Existing Functional Applications.

TABLE 3-22.

GMAP PDD USE BY APPLICATION

	Admin. and Assembly	Geometry	Shape Rep. (Topology)	Shape Element Incl. Form Features	Const. Geometry	Nonshape	Tolerances
Blade Applications							
Parametric Design	X	X	X	X	X	X	X
Casting Tooling		X	X	X	X	X	X
IBIS		X	X	X		X	
Disk Applications							
Disk Design	X	X	X	X		X	X
PROCAP	X	X	X	X			X
Feature-Based N/C and CMM Programming	X	X	X	X		X	X
Disk Forging	X	X	X	X		X	
IPC	X	X	X	X		X	X
Other Applications							
Case Boss N/C	X	X	X	X			X
Case Boss Inspection	X	X	X	X			X

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3.2.1.3.4 Disk Design

The disk design application would demonstrate how design/drafting data moved from initial design concept to final detail design. This application would also show how this data was intelligently interpreted and converted to GMAP format for exchange to demonstration applications downstream in the manufacturing process.

3.2.1.3.5 PROcess CAPability (PROCAP)

The PROCAP application would provide feedback to the engineering and process planning functions. The demonstration would show the use of unconventional PDD, such as features and tolerances, within the PDD Editor to retrieve the process capabilities of manufacturing operations that create similar features.

3.2.1.3.6 Feature-Based N/C Machining and CMM Inspection of Disk Features

The Feature-based N/C and CMM Programming application planned to use form feature entities, attributes and relationships in a GMAP model to produce source code programs for machining and inspecting disk features. This demonstration showed how GMAP PDD could enable more intelligent applications to be added to the life cycle.

3.2.1.3.7 Disk Forging

The disk forging application would demonstrate the electronic transmittal of a Supplier Report of Nonconformance (SRON) from a disk forging supplier to Pratt & Whitney, using GMAP. The electronic SRON would include a finished disk profile superimposed on the forging shape, and dimensions and tolerances affected by the nonconformance.

3.2.1.3.8 Retirement for Cause (RFC)

The RFC system is an automated, robotics-based inspection system developed by Systems Research Laboratories (SRL) in Dayton, Ohio, for the SA-ALC. More information on this application can be found in Task 3, Integrate Existing Functional Applications.

3.2.1.3.9 Boss Inspection Using Dimensional Measuring Interface Specification

Plans for the Engine Case Boss inspection demonstration involved the use of a CAD based geometric modeling environment, a case plumbing attachment boss PDD model, a neutral exchange system to communicate the product models, computer controlled dimensional inspection equipment, and a neutral interface to communicate inspection programs and data.

The primary objective of this demonstration was to show how a GMAP PDD model of an engine case boss can enable the automation of the inspection planning function. A secondary objective was to demonstrate the use of the Dimensional Measuring Interface Specification (DMIS) neutral format for communicating inspection programs from a CAD assisted inspection plan generation system to a computer controlled coordinate measuring machine. This demonstration was planned as a joint effort between Pratt & Whitney and Rensselaer Polytechnic Institute.

3.2.1.3.10 Case Boss N/C Programming

Plans also called for an engine case plumbing attachment boss to be built, transferred and used to generate and verify N/C programs for machining the boss. The primary objective of this demonstration would be to show that GMAP could support simpler, more typical parts than turbine blades and disks. Another goal would be to show that GMAP components could provide the PDD required by form feature-based applications.

3.2.1.4 Enhancements to PDDI Software

GMAP software was based on software developed for the PDDI project. Thus, enhancements to the PDDI software were required to support exchange system needs identified during the GMAP walkthroughs.

Enhancements or additions were identified in four areas:

- PDD model access
- Schema Manager
- PDD Editor
- System Translator performance improvements.

3.2.1.4.1 PDD Model Access

An enhancement to the PDDI MAS called the "Name/Value Interface" (N/VI) was designed to permit greater data independence in the software. This enhancement would enable more sophisticated applications to readily take advantage of the data richness in a PDD model by using an established, and maintained, set of access utilities.

The MAS supported access at the entity level. Applications desiring access to any part of the entity's attributes required the application to retrieve and return the entire attribute data block. Attributes were accessed by including the attribute's physical locations in the data block into the source code at compile time. The N/VI would require only the name and type of the attribute to be declared internally to the application. A call to the N/VI with the desired entity key would perform the physical mappings and accesses, and then return the attribute value only for that given attribute name.

Thus, the N/VI would free application programs from the need to be concerned with the physical location of attribute values within an entity in the working form of the product model. Using the N/VI, the only knowledge an application would require is the schema definition, the desired entity key, and the desired attribute's name and type. This would permit physical restructuring of the attribute data block to improve performance and storage costs without requiring any modification to application software.

The N/VI design consisted of three parts:

- Attribute data structures
- Direct query/store subprograms
- Procedural query subprograms.

The attribute data structures would be compiled into application programs, providing the definition of the N/VI data transfer block.

The direct query/store subprograms would be provided for applications that had high access and retrieval rates for only a few entities, and only specific attributes that they possess. The added overhead of mapping and small block size transfers would be balanced off against the newly gained application data independence. Binding to the schema would occur at run time by accessing the data dictionary.

Procedural query subprograms would be an access ability that applications could use to produce lists of entities that may have similar attribute values, such as a list of all 0.250" diameter holes. This would eliminate a great deal of the MAS chores and comparison strategy from the application and put them into the MAS. In this case, schema binding would occur at run time by accessing the data dictionary.

The MAS with N/VI is described in more detail in the GMAP System Specification (CI SS560240001U), System Design Specification (CI SDS560240001U), System Component As-built Product Specification Product Specification (CI PS560240032U), Model Access Software User's Manual (CI UM560240031U), and the System Components Operator's Manual (CI OM560240001U).

3.2.1.4.2 Schema Manager

Another enhancement to the PDDI software was the added capability to automatically create and maintain the conceptual schema and its implementations throughout the software modules. This capability was called the "Schema Manager". The existence of the Schema Manager would improve the flexibility of the software for both growth and development.

The Schema Manager was necessary to create entity definitions. The capability to query, modify, or delete these definitions and the ability to generate the physical schema (application view) from the conceptual schema were also required. The Schema Manager design included mechanisms to:

1. Isolate the interactive user interface from the mainline programs, minimizing the effort of implementing the Schema Manager on different terminals and enabling batch input

2. Modify the content of the metamodel elements, based on the experience gained from the original PDDI effort

3. Improve integrity and normalization by assuring uniqueness of names in the appropriate scope

4. Produce a run-time subschema for use by the N/VI to map a data request from application programs to the physical structure of an entity in the working form, and for run-time binding of the schema to the application

5. Produce Pascal Include Files to define a physical subschema in a format that can be inserted into a source program for compile time binding of the schema to the application

6. Produce a formatted report of the entity definitions contained in the conceptual schema.

The Schema Manager is described in more detail in the GMAP System Specification (CI SS560240001U), System Design Specification (CI SDS560240001U), System Component As-built Product Specification Product Specification (CI PS560240032U), Schema Manager User's Manual (CI UM560240011U), and the System Components Operator's Manual (CI OM560240001U).

3.2.1.4.3 PDD Editor

The PDD Editor was designed to populate PDD models with entities as defined in the schema. It could also create, modify, delete, and view the PDD contained in the working form model. The PDD Editor would bridge the gap between existing modelers that create conventional PDD, or a subset of the GMAP PDD, and those that are referred to as "product modelers," that support the complete spectrum of PDD as defined in the GMAP schema. This software was necessary to create the GMAP models for the demonstration applications, not to test the GMAP concepts or system components.

The PDD Editor was designed to use the graphics capabilities found in the IBM GraPhigs system. This graphics system provided complicated display functions and manipulation of graphical entities. The PDD Editor display capabilities include the display of geometric entities and their labels. Additional commands provide for the complete interrogation of displayable and nondisplayable entities in the PDD model.

The PDD Editor is described in more detail in the GMAP PDD Editor User/Operator Manual (CI U/OM560240031U), and the System Components Operator's Manual (CI OM560240001U/SCN-1).

3.2.1.4.4 System Translator Performance Improvements

The System Translator is a software mechanism developed under PDDI for passing data between dissimilar systems. The translator had a preprocessor which translated the internal working f rm from the sending system into an exchange format file, and a postprocessor which translated the exchange format file into the receiving system internal working form.

Enhanc. ents would also have to be implemented to make the System Translator conform to the PDES ex. ange format. During the program, several additional enhancements were made that reduced the CPU time for System Translator operation.

The System Translator is described in more detail in the GMAP System Specification (CI SS560240001U), System Design Specification (CI SDS560240001U), System Component As-built Product Specification Product Specification (CI PS560240032U), System Translator's User's Manual (CI UM560240021U), and the System Components Operator's Manual (CI OM560240001U).

3.2.2 Review Preliminary Design (Subtask 2.2)

Review of the progress and the technical adequacy of the GMAP system design was conducted as part of the the third IRB meeting during April 1987. The key information presented at that meeting was to explain the enhancements required to PDDI software that were required to support the GMAP interface architecture: the Schema Manager, the Name/Value Interface, the PDD Editor, and the System Translator. Also reviewed were the demonstrations planned to test the GMAP concepts.

3.2.3 Establish the Detail Design (Subtask 2.3)

3.2.3.1 Establish the Product Specifications

3.2.3.1.1 System Components

The GMAP System Component As-designed Product Specification (CI PS560240031U) established the design of the GMAP System Components. The document described the structure, functions, language, database requirements, interfaces and quality assurance provisions of the system components: the Schema Manager, Model Access Software with Name/Value Interface, and the System Translator.

The System Component As-designed Product Specification consisted of four volumes. Volume I contained:

- Section 1 — An introduction, describing the function of the primary GMAP/PDDI system components at a high-level, and summarizing this document.
- Section 2 — Reference documents and terms and acronyms used in this document.
- Sections 3 through 3.9 - A System Overview, IDEF0 Function models, application interfaces, program interrupts and other design details.

Volume II contained the routine listings for the Schema Manager. Volume III contained the routine listings for the MAS and N/VI. Volume IV contained the routine listings for the System Translator, and Quality Assurance provisions.

The GMAP System Component As-built Product Specification Product Specification (CI PS560240032U) presented the design of the GMAP System Components after the final software was built, tested, and debugged.

3.2.3.1.2 Retirement for Cause and Integrated Blade Inspection System

The GMAP-to-RFC Interface Product Specification (CI PS560240011U) and the GMAP-to-IBIS Interface Product Specification (CI PS560240021U) are discussed under Task 3, Integrate Existing Functional Applications.

3.2.3.2 Establish the Unit Test Plans

The GMAP-to-RFC Unit Test Plan (CI UTP560240011U) and the GMAP-to-IBIS Interface Unit Test Plan (CI UTP560240021U) are discussed in Task 3, Integrate Existing Functional Applications.

3.2.4 Perform Critical Design Review

A critical design review is usually conducted by the Air Force to determine if the detailed design satisfies all the requirements established in the System Design Specification, Product Specifications and other design documents. Because of the close coordination with the Air Force/IRB in establishing the detail design, no formal critical design review was performed on GMAP. However, an informal critical design review was conducted in January 1988 at Dayton, Ohio for the Air Force Project Manager.

3.3 Task 3 — Integrate Existing Functional Applications

Task 3 consisted of efforts similar to Task 2 (i. e., Preliminary Design, Detail Design) except that, in Task 3, work focused on the RFC and IBIS Interfaces rather than the GMAP system software components. The foundation for this work was traceable back to the walkthroughs conducted in the needs analysis and requirements definition conducted in Task 1.

Within the Logistic Support function, three separate areas were investigated. First, a subteam was formed to create a model of the San Antonio Air Logistics Center (SA-ALC). This subteam consisted of ITI investigators who interviewed personnel at SA-ALC.

The second and third subteams were formed to investigate two specific functional applications currently being installed at SA-ALC. These applications are the IBIS and RFC disk inspection system. IBIS and RFC were selected because they afforded the ability to investigate a process that was being automated, yet still had manual interface. IBIS and RFC could benefit from the development of a computer interface that provided the necessary PDD input.

The IBIS subteam consisted of representatives from ITI who interviewed SA-ALC and General Electric (Evandale, Ohio) personnel involved in the implementation and development of the IBIS system. The RFC subteam consisted of representatives from MCAIR who interviewed SA-ALC and Systems Research Laboratories personnel involved in the implementation and development of the RFC system. The findings, reported in the Needs Analysis Document (CI NAD560240001U) and System Requirements Document (CI SRD560240001U), were used to design the GMAP interfaces to RFC and IBIS.

3 3.1 Establish Interface to Disk Inspection

The RFC Interface prototype was included in GMAP to demonstrate that a PDD model transported via the GMAP system software can support the needs of the RFC logistics system. The RFC inspection system was developed by a team of aerospace companies headed by Systems Research Laboratories. The objective of the system was to provide the United States Air Force with a nondestructive evaluation capability to conduct consistently high reliability inspections on critical turbine engine components. This high reliability was essential to the "retirement for cause" philosophy which was to reuse expensive engine components until an unacceptable defect is found, instead of retiring those components at an analytically predetermined point.

The major operations of the RFC system were:

- generate a scan plan that provided both the geometry of areas on the disk targeted for inspection, and inspection paths on these areas for specific robotic cell (ultrasonic/Eddy current) inspection
- inspect the disk using ultrasonic/Eddy current robotic cells to collect anomaly data and potential flaws
- analyze the flaw data. Flaws were compared with flaw criteria to determine the status of the disk as acceptable, rejectable, or as inspection incomplete.

3.3.1.1 RFC Interface Preliminary Design

The RFC Interface provided PDD from the GMAP model to the RFC disk inspection system. The two major functions of the GMAP-to-RFC Interface were to:

1. Translate the GMAP disk model PDD from exchange format to working form in VAX computer memory

2. Translate the model in working form to the Unigraphics data base that is resident on the RFC system at Systems Research Laboratories.

A schematic of the RFC Interface using a part model transferred from Pratt & Whitney is illustrated in Figure 3-24.

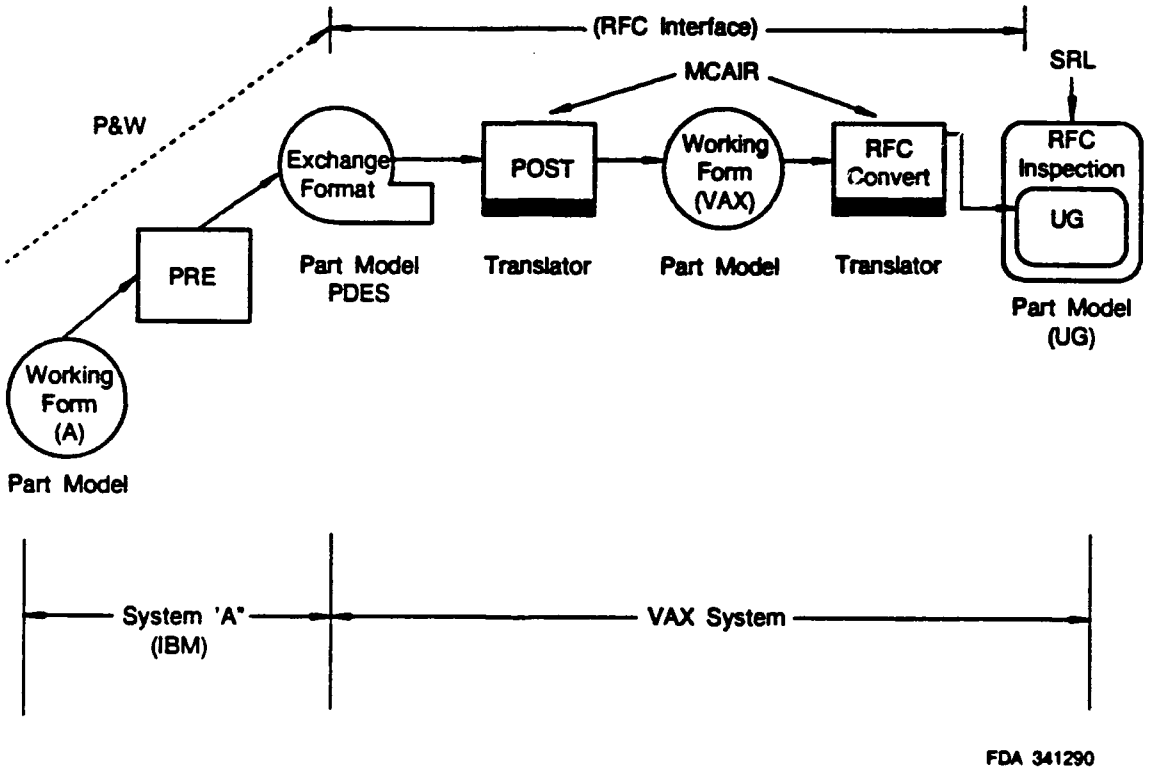

Figure 3-24. RFC Interface System

The PDD model provided the following data to support RFC scan plan generation and flaw data analysis:

- Complete 3-D geometric definition of the disk model
- Surfaced areas on the part targeted for inspection (zones)
- Inspection interval indicator (cycles)

- Standards and parameters for evaluation of potential flaw data collected during inspection (flaw criteria). (Flaw criteria specified maximum "acceptable for service" limits on flaw size, number of flaws per area, and flaw orientation for specific zones on the part. Flaw criteria were defined within two categories, surface flaws and internal flaws.)

The IDEF0 function modeling methodology used for modeling the product life cycle was also used with RFC. A hierarchical representation of the RFC Interface is shown in Figure 3-25 as a high level IDEF model.

- A-0, the RFC Software, translates the GMAP disk model from exchange format into a Unigraphics format model. This is a top system view. Component systems follow.

- A0, the RFC Interface, consists of the PDES Postprocessor and RFC Conversion Routines.

- A1, the PDES Postprocessor, converts the model from the exchange format into a memory resident working form.

- A2, RFC Conversion Routines, converts a working form model into Unigraphics format.

- A21, Initialize the Unigraphics model, logs the process into the Unigraphics File Manager and allows allocation of an empty Unigraphics file for the Unigraphics model that will be built by the RFC Conversion Routines.

- A22, Convert Entities, consists of four working form to Unigraphics conversion modules, grouped by specific entity categories to custom fit the program algorithm and GMAP schema. The calling order of these routines is important for the separation of noncycle entities from cycle entities to ultimately produce cycle-specific Unigraphics part files from the master GMAP working form model. The remaining unprocessed entities will be converted to Unigraphics groups with members and attributes that correspond to the entity relationships in the original working form model, using a "generic" algorithm.

- A221, Convert Simple Geometry, converts all simple curves in the working form model into corresponding curves in the Unigraphics model.

- A223, Convert Cycle Related Entities, deals with all cycle specific entities.

- A23, Terminate the Unigraphics Session, shows a standard filing and exit from the Unigraphics system.

A-0 RFC Software
A0 RFC Interface
A1 PDES Post Processor
A2 RFC Conversion Routines
A21 Initialize UG Model
A22 Convert Entities
A23 Terminate UG Session
A221 Convert Simple Geometry
A223 Convert Cycle Related Entities

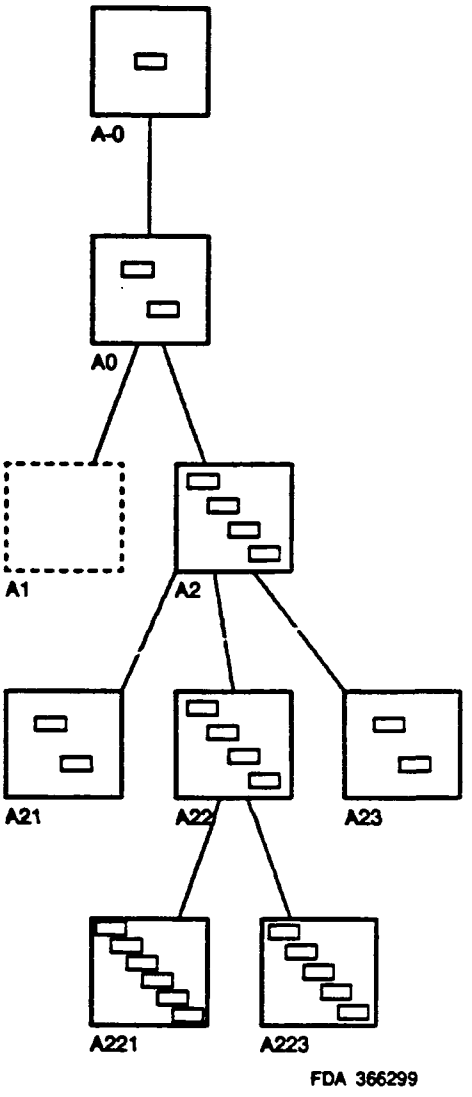

Figure 3-25. RFC Interface Block Diagram

A key component of the preliminary design was to produce a Development Specification for the prototype RFC Interface. The RFC Interface Development Specification (CI DS560240011U) described the functions, performance, environment, interfaces and design requirements for the RFC Interface. It detailed the requirements satisfied, was compatible with the System Design Specification design approach, and was traceable back to the System Requirements Document. The document described the RFC Interface in terms of: functional characteristics, performance characteristics, physical characteristics, interface characteristics, and design constraints.

Section 3 of the RFC Development Specification described the existing system environment and architecture and documented the to-be system developed for the end-of-contract demonstration. Section 3.2 described the hardware and software requirements; Section 3.3 detailed the functional requirements; and Section 3.6 described the data requirements of the to-be system.

3.3.1.2 RFC Interface Detail Design

The detail design work on the RFC interface led to the production of a Product Specification and a Unit Test Plan for demonstrating the effectiveness of the prototype RFC Interface.

A Product Specification was produced for each Development Specification. There were two versions of the Product Specification: the "As-designed" and the "As-built". The "As-designed" Product Specification and "As-built" Product Specification differed only in that the "As-built" Product Specification included all of the changes made to the "As-designed" version throughout the remainder of the project. Based on each Development Specification, the "As-designed" Product Specification established the design of the configuration item (RFC or IBIS) including structure, functions, language, data base, individual components, interfaces and quality assurance provisions, as applicable.

A Unit Test Plan was also produced for each Development Specification. The Unit Test Plan was traceable to each requirement as stated in the Development Specification. The Unit Test Plan assured that each requirement stated in the Development Specification would be adequately validated, and that the data generated during demonstrations would verify that the performance objectives were met.

3.3.1.2.1 RFC Interface Product Specification

The GMAP-to-RFC "As-designed" Product Specification (CI PS560240011U) was published in December 1987. The "As-built" Product Specification (CI PS560240012U) was published in February 1989. The main body of the RFC Product Specification discussed the processing, input and output parameters, and presented code for each of the routines in the RFC Interface.

3.3.1.2.2 RFC Interface Unit Test Plan

The GMAP-to-RFC Unit Test Plan (CI UTP560240011U) was published in December 1987. The Unit Test Plan assured that each requirement stated in the RFC Development Specification would be adequately validated, and that the data generated during demonstrations would verify that the performance objectives were met. The RFC Interface software was tested at four levels: Module, Program, Acceptance, and System Integration testing. Figure 3-26 indicates the testing level relationship. The RFC Unit Test Plan discussed each of these testing levels in detail.

Although there were no specific performance requirements for the RFC Interface, the modular design and software quality assurance procedures used in software development ensured that it was efficient and reliable. Therefore, there were no explicit performance tests to be performed. Plans called for producing problem reports, test logs, and test results during testing to assist in generating the Unit Test Report.

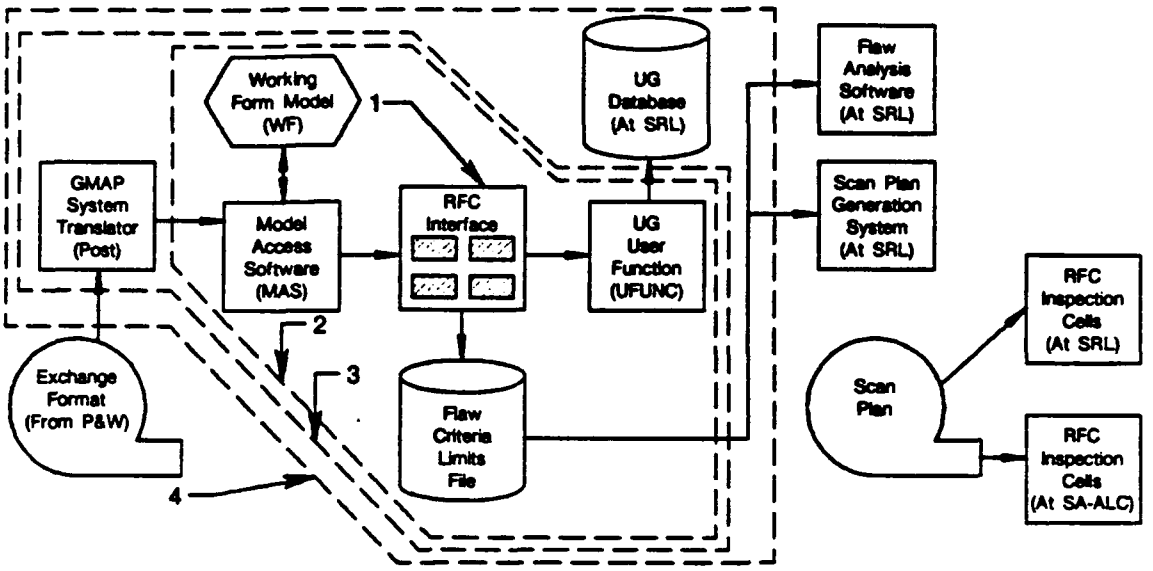

Figure 3-26. RFC Interface Testing Level Relationships

3.3.2 Establish Interface to Blade Inspection

The IBIS is a highly automated inspection system at the San Antonio Air logistics Center. The GMAP-to-IBIS Interface, built by ITI, provides PDD to the Inspection Plan Generation Subsystem (IPGS) of IBIS. It facilitates the inspection of in-service engine compressor blades for surface anomalies using fluorescent penetrant inspection.

3.3.2.1 IBIS Interface Preliminary Design

The GMAP-to-IBIS Interface was designed to perform the following tasks.

- Derive an IBIS-compatible, bi-cubic patch surface representation of the blade from the Non-Uniform Rational B-spline (NURB) surface representation contained in the GMAP model
- Extract the flaw criteria and inspection zone information from the GMAP model and make them available to the IPGS.

The IBIS Interface then provided two types of information to the IPGS using a GMAP blade model as input:

- External surface data needed to inspect the blade surfaces correctly
- Inspection criteria information needed to determine the disposition of the blade after inspection.

Blade geometry was provided to IBIS in an electronic, IPGS-native format. Flaw criteria and inspection zone information was provided in an electronic, textual format.

A schematic of the IBIS Interface architecture is illustrated in Figure 3-27. A hierarchical representation of the IBIS Interface is shown in Figure 3-28 as a high level IDEF0 functional model.

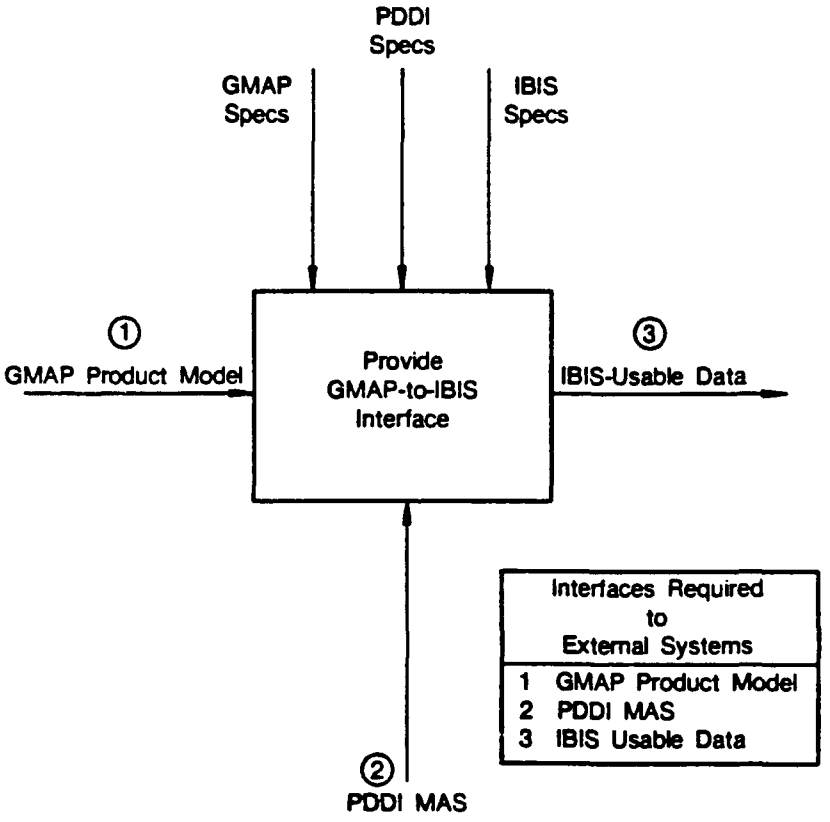

Figure 3-27. GMAP-to-IBIS Interface Architecture

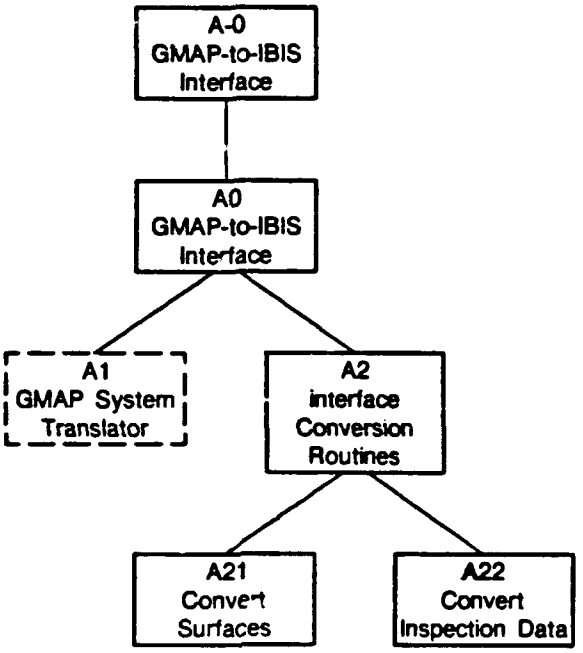

Figure 3-28. IBIS Interface Block Diagram

A-0, the GMAP to IBIS Interface, converts the GMAP compressor blade model from the exchange format into an IBIS specific data format file, and an IBIS inspection data file. This is a top system view. Component systems follow.

- A0, the GMAP to IBIS Interface, consists of the GMAP System Translator and the Interface Conversion Routines.
- A1, the GMAP System Translator, converts the model from the exchange format into a memory resident, random access working form.
- A2, the Interface Conversion Routines, converts the working form into IBIS format.
- A21, Convert Surfaces, consists of two functions. The first, converts all rational b-spline surfaces into parametric spline surfaces. The second, converts the parametric spline surfaces into bi-cubic patch surfaces.
- A22, Convert Inspection Data, consists of two working form to inspection information conversion procedures. The first converts all flaw criteria information. The second deals with the conversion of all inspection zone definition data in the model.

As with the RFC Interface, a key effort in the preliminary design was to produce a Development Specification for the IBIS Interface prototype.

The IBIS Interface Development Specification (CI DS560240021U) described the functions, performance, environment, interfaces and design requirements for the IBIS Interface in much the same manner as the RFC Development Specification.

Section 3 of the IBIS Development Specification described the to-be system developed for the end-of-contract demonstration. Section 3.1.2 defined the GMAP-to-IBIS Interface requirements. This Interface actually consisted of three separate interfaces. They were:

1. GMAP Product Model
2. MAS and N/VI
3. IPGS.

The detailed functional requirements for these interfaces are contained in Section 3.2 of the IBIS Development Specification. That section also discussed the required inputs, processing, and outputs.

3.3.2.2 IBIS Interface Detail Design

As with the RFC Interface, the detail design work on the IBIS Interface led to the production of a Product Specification and a Unit Test Plan for demonstrating the effectiveness of the prototype IBIS Interface.

3.3.2.2.1 IBIS Interface Product Specification

This specification established the design of the GMAP-to-IBIS Interface. The GMAP-to-IBIS "As-designed" Product Specification (CI PS560240021U) was published in March 1988. The "As-built" version (CI PS560240022U) was published in February 1989. With the use of functional flow diagrams, the main body of the Product Specification discussed the detailed functional requirements of the GMAP-to-IBIS Interface including input, processing, and output requirements.

The Product Specification also included descriptions of four distinct logical modules comprising the interface, each consisting of a number of routines:

1. GMAP to IBIS Interface Control Module
2. GMAP System Translator
3. working form to IBIS Specific Data Format File Conversion Module
4. working form to IBIS Inspection Data File Conversion Module.

3.3.2.2.2 IBIS Interface Unit Test Plan

The GMAP-to-IBIS Interface Unit Test Plan (CI UTP560240021U) assured that the performance objectives stated in the Development Specification would be adequately validated.

The GMAP-to-IBIS Interface software was tested at four levels:

1. Module (subprogram) testing
2. Program testing
3. Acceptance testing
4. System integration testing.

The first three levels verified the GMAP-to-IBIS Interface. The fourth level verified the overall GMAP concepts. Figure 3-29 illustrates the relationship of the testing levels.

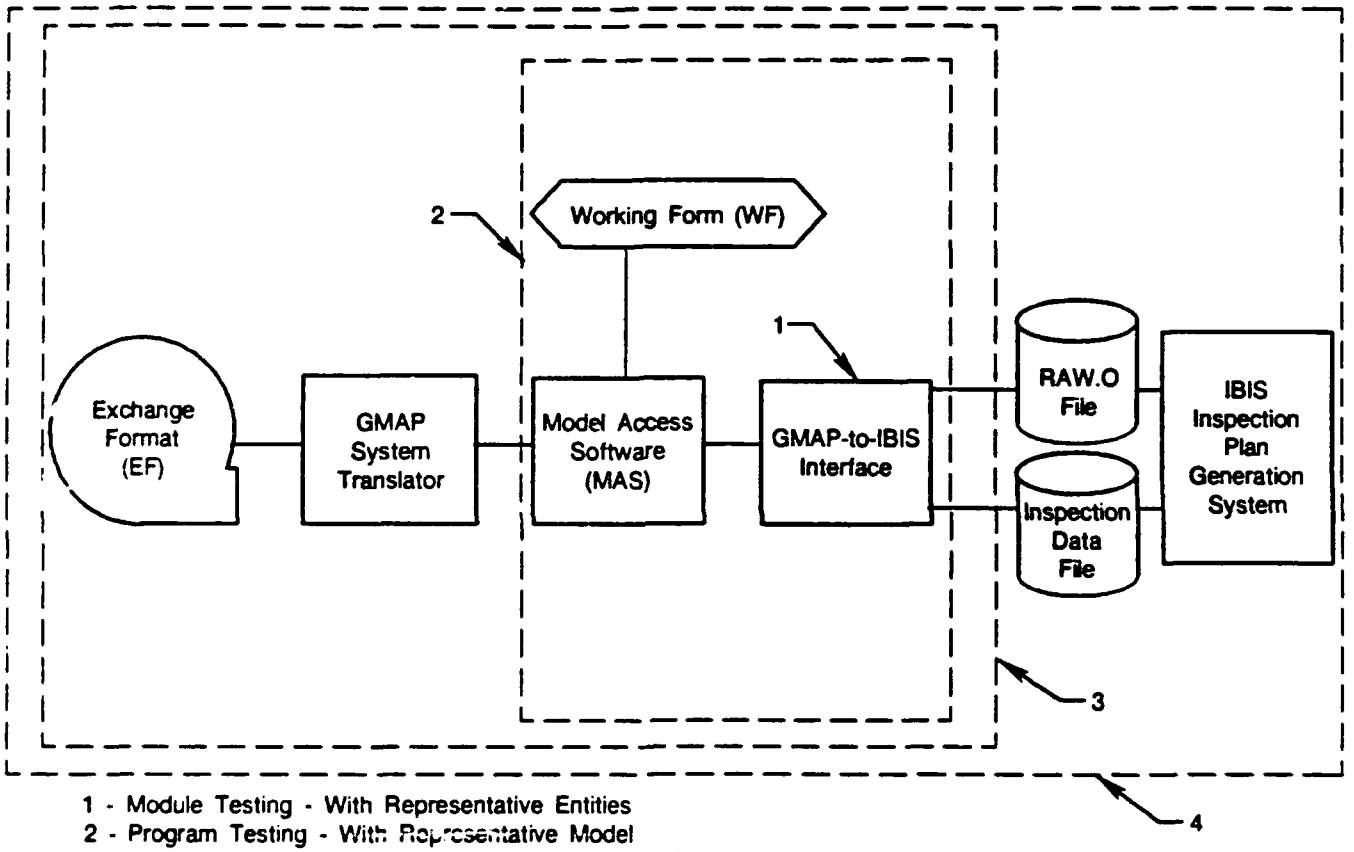

Figure 3-29. IBIS Testing Level Relationships

3.4 Task 4 — Build and Integrate the Applications Interface

Under Task 4, GMAP software was constructed and the function, performance, and integration of the system was verified in accordance with the system and unit test plans established in Tasks 2 and 3. Applicable manuals were produced for the installation and operation of the system.

3.4.1 Construct Software

The foundation of the GMAP system was the software originally built and tested under the PDDI program conducted by McDonnell Douglas. This included the MAS, the System Translator, as well as the data dictionary and PASCAL include files. Task 2 identified the enhancements necessary to the basic PDDI software for the more complex parts in GMAP and to encompass the entire product life cycle. Summarized below is the software that comprises the GMAP system. Figure 3-30 illustrates the relationship of this software in a diagram of the GMAP system architecture. Table 3-23 lists the systems on which the software components were implemented and the version numbers of each.

- **System Translator** — A software mechanism used for communicating data between dissimilar systems initially developed under PDDI and enhanced in GMAP.

- **Name/Value Interface added in GMAP to the PDDI MAS** — The MAS is a set of routines that allow access to product models for creation, modification, deletion, and navigation at the entity level. The N/VI is a set of PASCAL subroutines that help query the PDD model about entity attributes. It frees the application programs from the need to know the physical location of an attribute for an entity. It provides access at the attribute level.

- **Schema Manager** — One of two new components developed in GMAP, it creates the data dictionary and PASCAL include files. These are the physical files that define the data schema to the system components and applications.

- **PDD Editor** — The second of two new components developed in GMAP, it adds PDD such as geometry, tolerances, form features, administrative and assembly data, etc. to demonstration models for each application from Data Dictionary definitions.

- **Data Dictionary** — A listing of all the possible entity types and attributes that could occur in any model including their names, data types, size, attribute displacements, and usage.

- **PASCAL Include Files** — Representations of the Data Dictionary for use in PASCAL application programs. The Data Dictionary is used primarily for FORTRAN programs.

- Interfaces to the Air Force's RFC and IBIS at the San Antonio Air Logistics Center.

3.4.2 Construct Models

To complete the GMAP system, testing was conducted according to the System Test Plan with actual complete PDD models.

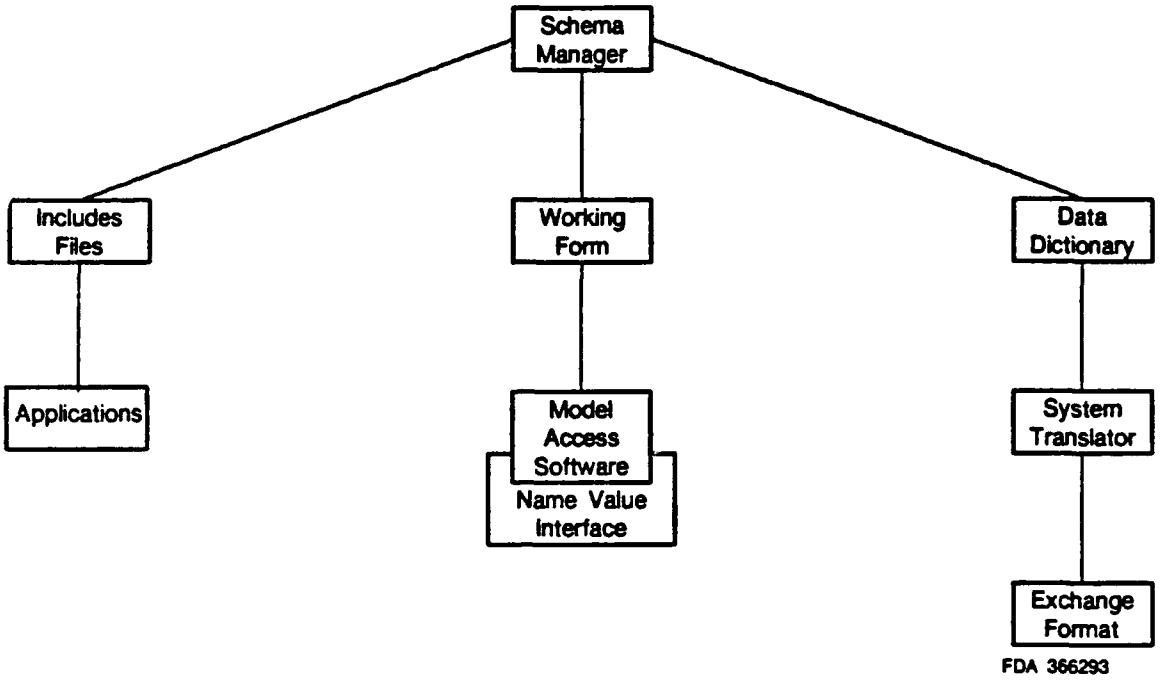

Figure 3-30. GMAP System Architecture

Commercial modeling systems in use at Pratt & Whitney were used for the initial geometry and topology creation of the GMAP PDD models. This included the use of the IBM CAEDS, the Computervision CADDS4X, and the MCS ANVIL 4000 systems. Additional PDD, such as tolerances, nonshape, form features, and so on were added by the PDD Editor where required. For example, Figure 3-31 illustrates the process whereby the complete turbine blade model was populated by use of PDD Editor interaction with the Data Dictionary. Those models are summarized in the paragraphs that follow. More comprehensive descriptions can be found in the GMAP Demonstration Model Description document (TTD560240001U).

3.4.2.1 Disk Design Model

The Disk Design model was created on a SUN-based Computervision CADDS4X CAD/CAM system at Pratt & Whitney. This model was generated starting with a cross-section of the disk shape. The disk was a turned part that was partially represented by a BOR object. A BOR is a complete topological representation of a 2-D turned part. A full representation requires bolt holes, scallops, and other nonturned features to be represented as 3-D features.

TABLE 3-23.

GMAP SOFTWARE PLATFORM MATRIX

Software	Operating System	PDDI Version		GMAP Version
		Original	Extension	
Schema Manager	IBM/MVS		3.0	4.0
	IBM/CMS			4.0
Model Access Software	IBM/MVS	2.0	3.0	4.0
	IBM/CMS	2.0	3.0	4.0
	VAX/VMS	2.0	3.0	4.0
	UNIX	2.0		
Name/Value Interface	IBM/MVS			4.0
	IBM/CMS			4.0
	VAX/VMS			4.0
System Translator	IBM/MVS	2.0	3.0	5.0
	IBM/CMS	2.0	3.0	5.0
	VAX/VMS	2.0	3.0	5.0
	UNIX	2.0		
Data Dictionary	IBM/MVS	2.0	3.0	4.0
	IBM/CMS	2.0	3.0	4.0
	VAX/VMS	2.0	3.0	4.0
	UNIX	2.0		4.0
PASCAL Include Files	IBM/MVS	2.0	3.0	4.0
	IBM/CMS	2.0	3.0	4.0
	VAX/VMS	2.0	3.0	4.0
PDD Editor	IBM/CMS			4.0
IBIS Interface	VAX/VMS			1.0
RFC Interface	VAX/VMS			1.0

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The BOR object with 3-D features, tolerances, and notes was sufficient information to represent the disk for downstream applications. The BOR underlying 2-D profile was revolved about an axis, creating a full 3-D model for the applications requiring surfaces.

The disk model was output from the Computervision system as a GMAP exchange format file. This was possible since the MAS and System Translator were ported to the Computervision system. In the the exchange format, the model was available for the other disk-related GMAP demonstrations.

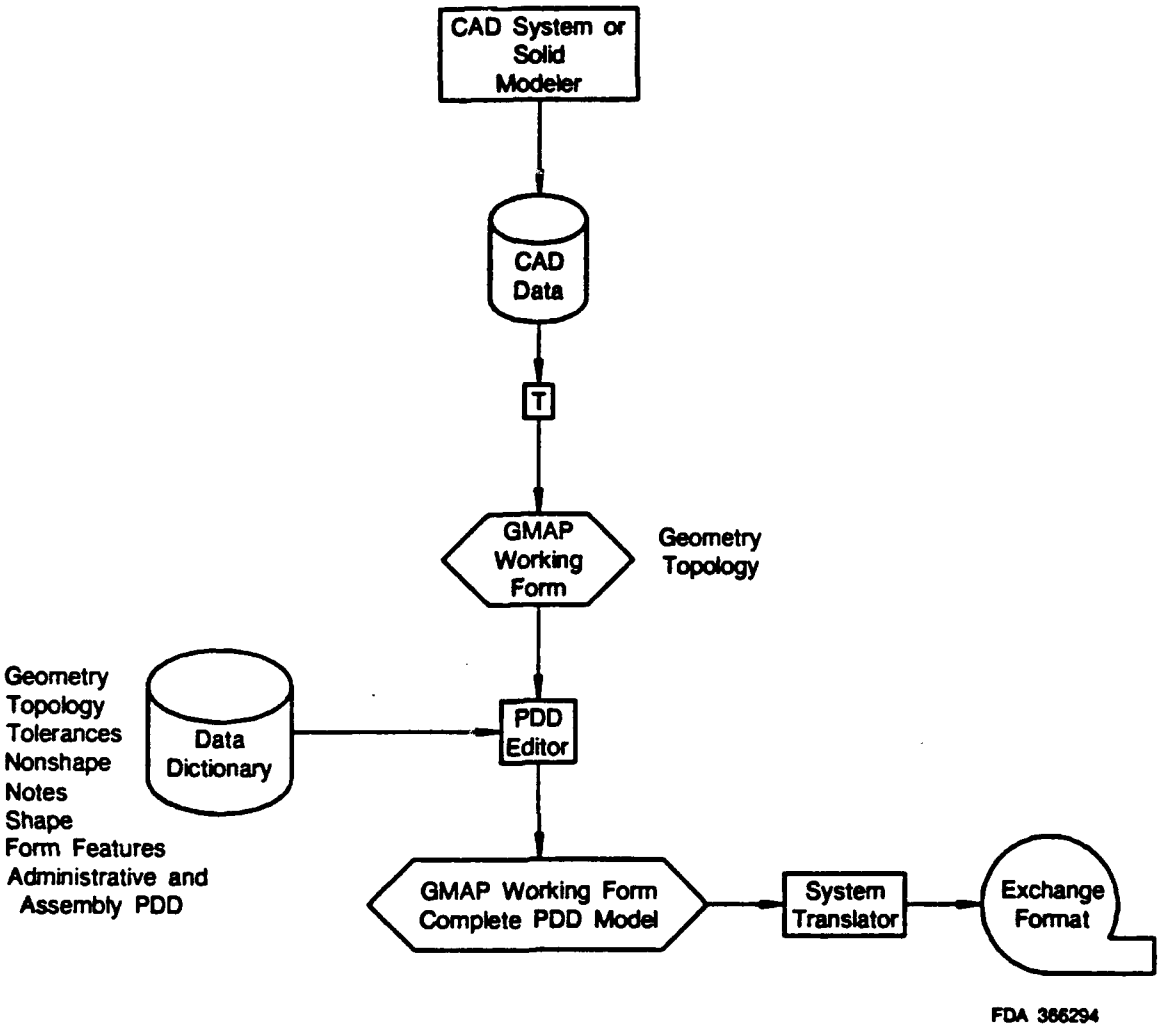


Figure 3-31. PDD Editor Interaction With the Data Dictionary

3.4.2.2 Process Capabilities Model

The PROCAP model was a F100 1st-stage disk. This model contained geometry, BOR topology, form features, tolerances and Administrative information. Geometrically, it was described by a contiguous 2-D curve string. Elements of the curve string were 2-D open curves. These curves underlied topological BOR FACES and FACES which are shape elements. Tolerances were attached to FACES via an topological representation, in this case, BOR FACES were combined in the PDD Editor and were designated as form features, such as inner diameters and outer diameters.

3.4.2.3 Feature-based N/C and Coordinate Measuring Machine Model

The Feature-based N/C and CMM model was a three dimensional model of the F100 1st-stage disk counter balance weight flange consisting of holes and scallops. The scallops were

modeled as 3-D DRIVEN FEATURES based on geometric extrusions that were replicated around the entire disk via the CIRCULAR_FEATURE_PATTERN entity. Similarly, the holes were modeled as THRU_HOLE3s that were replicated around the disk via the CIRCULAR_FEATURE_PATTERN entity. Tolerances and datums were also in the model for a CMM application.

3.4.2.4 GMAP-to-RFC Interface Model

The GMAP PDD model for the RFC system included a BOR representation of the disk body. This 2-D representation contained geometry and topology and provided sufficient information to produce a full 3-D BOR. Inspection zones for the RFC system were also included in the model. These zones had associated external and internal flaw criteria required by the RFC system. Notes from the engineering drawing, as well as administrative data, were also included. These notes were embodied as GMAP nonshape entities and included tolerances and datums.

3.4.2.5 Disk Forging Model

The Disk Forging model was built by Wyman Gordan using ANVIL 4000 on a VAX computer system. The model was then modified to contain nonconforming characteristics. Business data and other required technical data were added to the ANVIL part file using available ANVIL entities, such as text, in conjunction with level assignments. The technical data, typical of the disposition process, included administrative information, geometry, forge shape, finished shape, and features.

A special purpose translator was used to translate the ANVIL part file into the GMAP working form. After creating the working form, the model was translated to exchange format for transmittal to Pratt and Whitney.

3.4.2.6 Parametric Blade Design Model

The parametric blade design model was an F100 1st stage turbine blade. The turbine blade geometry and topology were built at Pratt & Whitney in the CAEDS solid modeler on an IBM computer. Design system translators converted raw design data from several different files into CAEDS program file format. The CAEDS solid model was run through the CAEDS SUPERTAB option to create a BREP model. The model was then output as a CAEDS universal file which was converted into the GMAP working form by a translator written for this purpose. There, a representative sample of Notes, Tolerances, Specifications, Datums and Form features were added to the model using the PDD Editor to complete the model.

It was impossible to create one complete PDD model of the turbine blade, either in CAEDS or the PDD Editor, because of model size. If the complete turbine blade model were built, it would need approximately 46M of memory and approximately 78M of disk space for storage, of which 98 percent was geometric entities. Therefore, this model was built in four pieces and redundant PDD were omitted. The four models were: airfoil with internal cooling features, platform, shank, and attachment.

A CAEDS restriction on the number of facets in a solid limited our ability to model the entire part. This restriction prohibited the addition of much of the detailed geometric entities such as fillets, trip strips (extrusions), and cooling holes.

3.4.2.7 Casting Tooling Electrical Discharge Machining Electrode Model

The EDM electrode model was a 3-D model consisting primarily of free form curves and surfaces. Geometric entities in the model were combined via the explicit feature entity to communicate application specific features. Ribs, airfoil parting surfaces, and trip strips are examples of applications features. The model consisted of five application specific features: airfoil upper surface, airfoil parting surface, ribs, trip strips, and tooling base.

3.4.2.8 GMAP-to-IBIS Interface Model

The IBIS model consisted of an accurate and complete description of the blade external surfaces. These were represented by 3-D free form BREP surfaces. The inspection zones and related geometry were also included in the model. Inspection criteria, surface flaw criteria and surface flaw limits in the model were associated to inspection zones and, therefore, related blade geometry.

3.4.2.9 Boss N/C Programming Model

The Boss N/C model was a model of a jet engine case plumbing attachment boss. This is the same model used in the Boss inspection demonstration with additional form features to enable N/C machining. The complete product definition of the model was created in the PDD Editor. Geometry and topology were represented using the GMAP BREP representation. The geometry and topology element were grouped under form features. Attached to the form features, geometry and topology were the datums and tolerances.

The product model working form was built at Pratt & Whitney and translated into exchange format. It was converted back to working form at Automation Technology Products (ATP).

The data from the product model was then used at ATP to build a CIMPLEX model, from which N/C programs for the case boss were generated. The part was subsequently machined at Ingersoll.

3.4.2.10 Boss Inspection Model

The Boss Inspection model was a model of the engine case plumbing attachment boss. The complete product definition model of the boss was created in the PDD Editor at Pratt & Whitney. Geometry and topology were represented using the GMAP BREP representation. The geometry and topology elements were grouped under the GMAP form features. The datums and tolerances are attached to the form features, geometry and topology.

3.4.3 Test System

Testing of the individual GMAP system components as well as the integrated GMAP system through application demonstrations is described in detail in the GMAP System Test Report (CI STR560240001U). The System Test Report discusses the Test Approach, Test Objective, Test Environment, Methods to Determine Quality of Results, and finally, the Test Results for each component test and application demonstration.

3.4.3.1 New/Enhanced System Components

In general, testing of the Schema Manager verified functionality for the following capabilities:

- Interactive entity creation
- Interactive entity update
- Interactive entity review
- Generation of files/reports from entity definitions:
  - Conceptual Schema report
  - PASCAL Include files
  - Run-time subschema file
  - Data Dictionary file
  - File and retrieval of schema master file.

The following Schema Manager functions, developed under the PDDI Extension project effort were also verified:

- Batch interface
- Model query utility.

The majority of the MAS was developed and tested in the original PDDI Project. These tests are documented in the PDDI System Test Report (STR560130000) dated 30 July 1985. Additional testing was performed only to verify fixes and provisions for the N/VI.

The N/VI provides the following capabilities:

- DIRECT QUERY SUBPROGRAMS, called by application programs to query an attribute value for a specified entity (including an attribute for a constituent entity)
- DIRECT STORE SUBPROGRAMS, called by application programs to replace an attribute value for a specified entity (including an attribute for a constituent entity)
- PROCEDURAL QUERY SUBPROGRAMS, called by application programs that require a list of entities with a specified attribute value (including an attribute for a constituent entity).

Testing of the N/VI followed the criteria established in the System Test Plan and the N/VI Unit Test Plan appended to the System Test Plan. The detailed test procedures consisted of a computer program to perform the required steps. The specific data entered, the expected results, and the actual results were documented in the N/VI test log. Any deviations found were entered in a discrepancy report and corrected. The test results verified functionality for the three capabilities.

The original PDDI System Test Plan was slightly modified and used in Acceptance Testing (Phase 3) of the System Translator to ensure that the GMAP Translator was tested under the same criteria as the original PDDI Translator. These tests were successfully completed.

In addition, the GMAP System Translator (Version 4) was used in the application demonstrations. Subsequent to the completion of the application demonstrations, the System Translator was modified to further enhance its performance. This new Version 5 System Translator was delivered under the contract.

The functionality of this new System Translator was verified through the use of a series of round-robin tests. Model verification was also performed using the Version 5 Translator. The increased performance of this Translator allowed a large number of models to be processed. The completeness and accuracy of the translation was verified with a utility developed for this testing.

Informal testing and debugging of the PDD Editor occurred jointly between Pratt & Whitney and ITI during PDD model building. Formal testing and debugging of the PDD Editor were performed according to a test plan specific to the Editor. The results of the PDD Editor testing showed that all entities were created, modified, and/or maintained as per the GMAP schema specification.

3.4.3.2 Applications

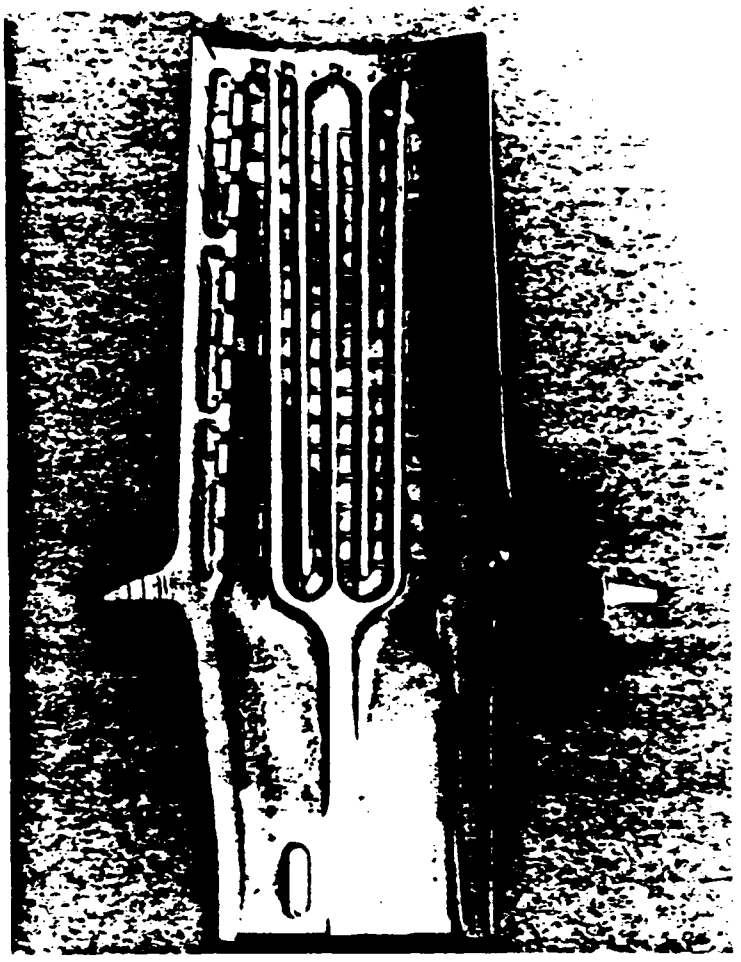
The objective of the test applications was to verify the functionality of the technology developed under GMAP in actual product life cycle situations. Several applications were selected to address each of the parts of concern: blades, disks, plumbing attachment bosses, and parts initially used in the PDDI program. Demonstrations of these applications were videotaped to provide permanent documentation. These tapes can be obtained from the Air Force ICAM Library.

3.4.3.2.1 Parametric Cooled Turbine Blade

This application focused on an F100 1st stage turbine blade such as that described in paragraph 3.4.2.6 and shown in Figure 3-32. Using the CAEDS solid modeler, an improved design method for this blade was demonstrated by directly translating design data, parametrically generating and modifying geometry, and finally, by preparing a complete part model through use of the PDD Editor. The resulting PDD model, which contained geometric and nonshape data, was a source for subsequent GMAP blade life cycle application demonstrations. The procedure is illustrated in Figure 3-33.

There were four specific objectives in blade design procedure:

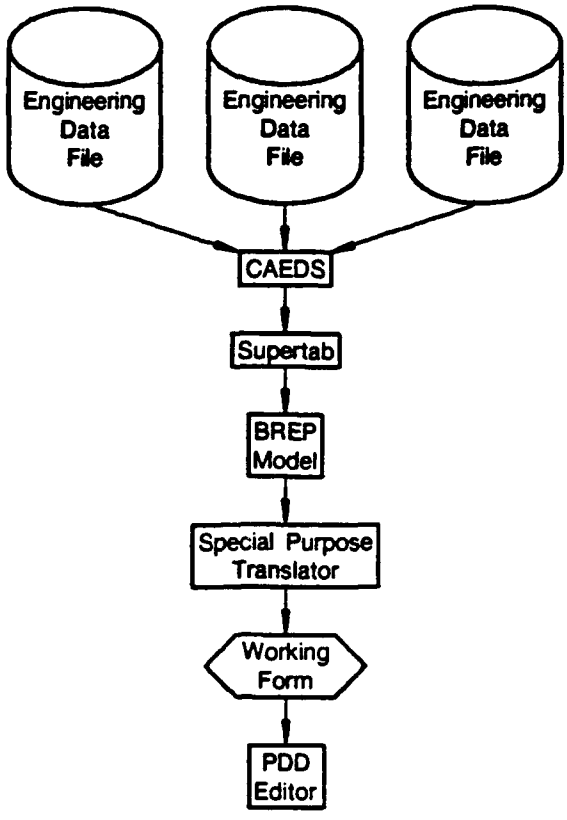
1. Verify the design system translators contained the appropriate source data along with the appropriate geometric construction commands
2. Verify that the CAEDS solid model was geometrically accurate
3. Verify that the BREP model data were consistent with the solid model
4. Verify that the PDD model contained geometry consistent with the BREP model and also to verify the accuracy and completeness of the nonshape data added by the PDD editor.



FC 96263

Figure 3-32. Internal Design Features of the F100 1st-Stage Turbine Blade

The solid model generated by CAEDS produced results that were within the limits expected. The horizontal cuts at defining sections produced results within 0.0001 inch. The horizontal cuts at nonkey locations showed a maximum difference of 0.0003 inch. This greater variation was somewhat expected due to inherent splining differences. These horizontal cuts also showed that cooling hole diameters and locations agreed precisely with the source data. Vertical cuts showed that core rib geometry was within 0.0005 inch of the source data. The trip strip profiles and locations agreed precisely with the source data. Verification of the accuracy and content of PDD model entities, both geometric and nongeometric, was successfully accomplished using the PDD Editor's "verify entities" function.



FDA 366295

Figure 3-33. Parametric Blade Design Procedure

3.4.3.2.2 Casting Tooling

The Casting Tooling application dealt with the manufacture and inspection of an EDM Electrode, shown in Figures 3-34. This electrode was used to machine the core in a mold as part of the turbine blade casting process. The part creates the complex geometry of the upper surface of the blade cooling cavity. This was one of the most critical and difficult applications in the manufacture of turbine blades.

The entire casting tooling application consisted of four applications:

- **Supplier N/C Machining.** Mold Masters of Mentor, Ohio, a Pratt & Whitney casting tooling supplier, used a GMAP model to machine the electrode, demonstrating supplier base integration.
- **Internal N/C Machining.** An internal Pratt & Whitney group used the same GMAP model to machine an electrode.
- **CMM Inspection.** The upper surface of each electrode was inspected using the GMAP model.

- **Automated Optical Inspection.** The electrode ribs and trip strips were inspected by Optical Gaging Products using the same GMAP model.

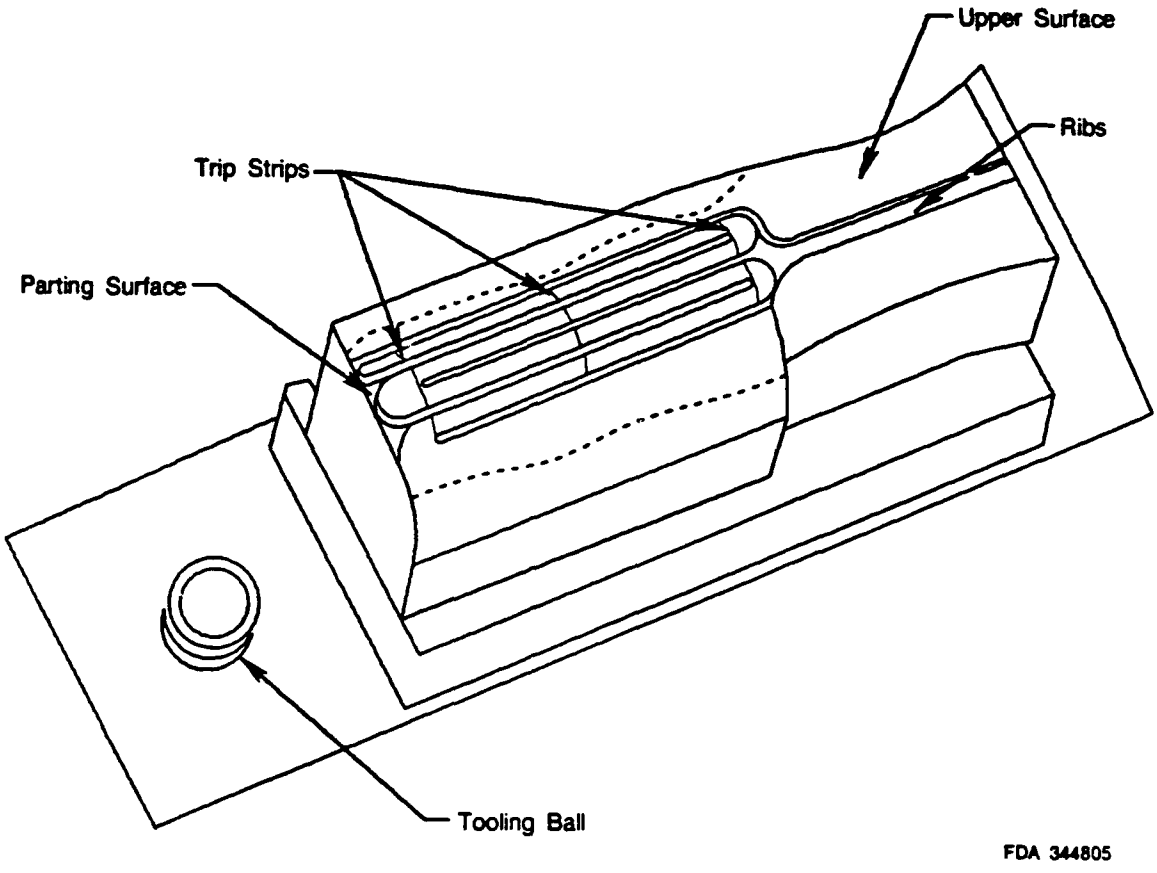


Figure 3-34. EDM Electrode Used in Casting Tooling Demonstration

The procedure and design data used to create the turbine blade model in the Parametric Cooled Turbine Blade Design demonstration were also used to create a model of the EDM electrode in CAEDS. The CAEDS part was then translated to working form using a CAEDS to working form translator written by ITI. Additional PDD was added to the working form model using the PDD Editor.

3.4.3.2.2.1 Supplier N/C Electrode Machining

An exchange format version of the EDM electrode was created by Pratt & Whitney and sent to Mold Masters, Inc. To enable Mold Masters to utilize the model, it was necessary to install the System Translator on their Computervision workstation. This allowed the creation of a working form version of the model on Mold Masters' SUN/UNIX platform. An application-specific translator developed by Pratt & Whitney with Computervision support was then used to translate the GMAP model into a CADDS4X model. An interface diagram of the application demonstration is shown in Figure 3-35.

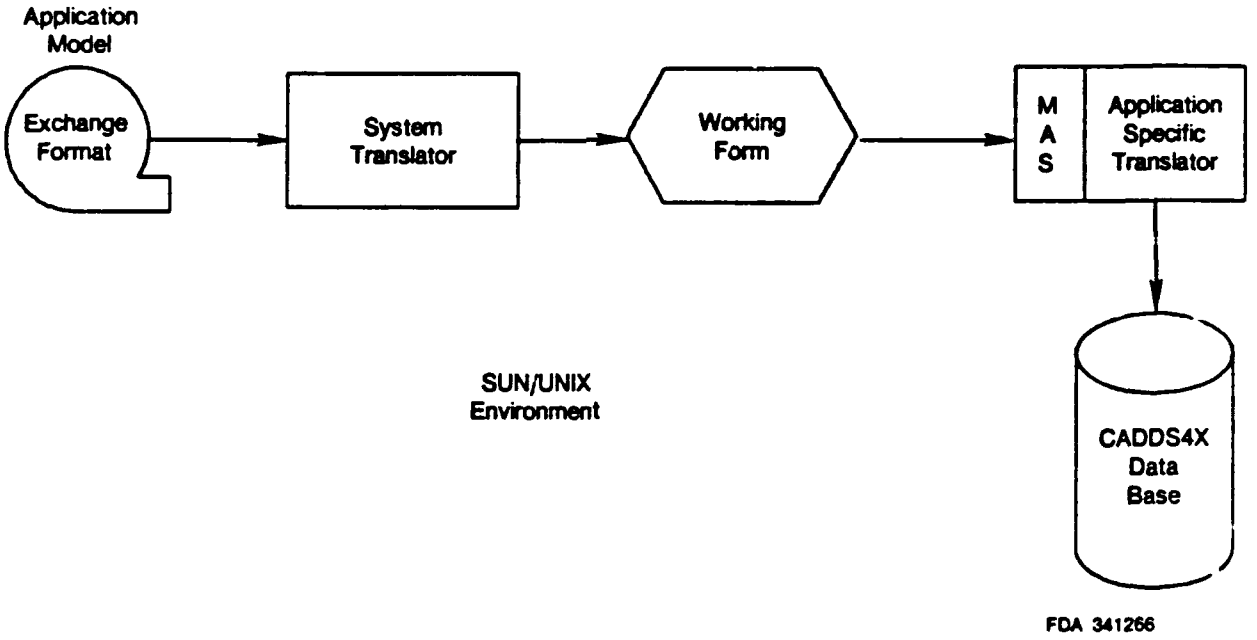


Figure 3-35. Supplier N/C Electrode Machining Demonstration Diagram of Interfaces

Qualification tests were performed to validate the results of the translation process. Once the translation process had been verified, Mold Masters created N/C programs using the NURB curves and surfaces provided by the GMAP model. These N/C programs were used to machine the electrode.

The machined electrode agreed with the GMAP product model within typical manufacturing tolerances. In-process inspections were performed periodically to control machining variables such as tool wear. The electrode was also inspected at process completion to verify that it was consistent with the original GMAP product model. The results indicated that the geometric integrity of the EDM electrode models was maintained throughout the modeling and translation process.

3.4.3.2.2.2 Internal N/C Electrode Machining

An application specific translator was used to translate the GMAP model into an ANVIL 4000 model. This application-specific translator made extensive use of the Cox-deBoor algorithm to extract points from the GMAP-supplied free form curves and surfaces. These points were then used to accurately reconstruct the geometry on the ANVIL system.

Qualification tests were performed to validate the results of translating the GMAP model to an ANVIL 4000 model. These tests verified that geometry had been translated with sufficient accuracy to ensure accurate N/C machining of the EDM electrode.

Numerical control programs were developed using the curves and surfaces generated by the GMAP System Translator. These N/C programs were used by an in-house machining group to

machine an electrode. This produced an electrode which agreed with the GMAP product model within typical manufacturing tolerances. This electrode was used in the automated inspection demonstrations.

3.4.3.2.2.3 CMM Inspection

This test was one of two inspections of the EDM electrodes machined in the supplier and in-house N/C machining demonstrations described above. In this inspection, a Digital Electronic Automation (DEA) CMM was used to inspect the upper surface of the electrode.

The CMM was programmed to inspect points on the upper surface of the electrodes at various cross sections. The measured points were compared to the tolerance requirements dictated by the product module to verify the machined surface accuracy.

Geometry, form feature, and tolerance data were accessed from the working form model of the EDM electrode using the MAS. This information was processed by a tool and die inspection planning program which prepared the inspection machine control data. The control data consisted of the electrode's datum reference frame, cartesian surface points on the surfaces to be inspected, corresponding surface normals, and tolerances.

The control file was used by a generic tool and die measuring program to drive the CMM. The CMM program aligned to the datum system dictated by the product definition, moved to each nominal surface inspection point, and probed the location of the actual surface. CMM inspection of the two machined electrodes verified that they were consistent.

3.4.3.2.2.4 Automated Optical Inspection

This demonstration was also used to inspect the EDM electrodes machined in the supplier and in-house N/C machining demonstrations described above. An Optical Measuring Machine (OMM), manufactured by Optical Gaging Products Inc., (OGP) was used to inspect the electrode ribs and trip strips.

The OMM was programmed to measure the location, width, and depth of the features machined into the electrode's upper surface. The measurement results were compared to the tolerance requirements dictated by the product definition to complete verification of the electrode's accuracy.

Geometry, form feature, and tolerance data were accessed from the working form model of the EDM electrode using the MAS. This information was processed by the tool and die inspection planning program which prepared the inspection machine control data. The control data for the OMM consisted of the electrode's datum reference frame, cartesian surface points on the features to be inspected, corresponding surface normals, and tolerances. The control data were used to create inspection macros using the DMIS language. The DMIS macros were converted to the native control language of the OMM using a DMIS postprocessor. The native language drove the OMM through the various alignment and measurement sequences.

3.4.3.2.3 Integrated Blade Inspection System

The GMAP-to-IBIS Interface reads an exchange format file that describes a turbine engine compressor blade, and produces one or more output files that could be used in the IBIS system

for generating inspection plans that drive blade inspection operations. The exchange format file is read and put into the working form by the System Translator postprocessor. The GMAP-to-IBIS Interface then converts the working form into one or more IBIS readable files.

Testing was performed to verify the Interface's function and quality in three areas.

1. **Accuracy** — The mathematical correctness of the entities translated. This is very important because the results of mathematical calculation were used to drive the closely toleranced movements of an inspection robot.

2. **Data Structure** — The correct relationships between data used to describe the blade surfaces and data used to describe the technical order inspection zones.

3. **Destination** — The assignment of different data to the correct IBIS data model. Specifically, verification that blade geometry data and blade inspection information reside in the correct files. The interpretation and grouping of entities related to blade geometry and inspection zones, etc. is an important function of the GMAP-to-IBIS Interface.

The GMAP-to-IBIS Interface was tested at two locations. The first three levels of testing, (Module level, Program level, and Acceptance level) were accomplished at ITI facilities in Milford, Ohio.

The Last level of testing, System Integration level, was performed at the SA-ALC in Kelly Air Force Base, Texas. SA-ALC personnel then used the IBIS files produced by the GMAP-to-IBIS Interface to produce the inspection plan to inspect the demonstration part.

The GMAP-to-IBIS Interface passed all of the executable tests and has proven its benefit to the inspection plan generation process at the SA-ALC.

3.4.3.2.4 Disk Design

The disk design application dealt with the F100 turbine disk. The procedure assumed that most of the preliminary design and analysis work had been completed. This effort consisted of work previously done with Pratt & Whitney proprietary software executed on an IBM 3090 mainframe or on a SUN based Computervision workstation. The file format of the disk design was a computerized disk file.

The computerized disk file was read into a SUN based Computervision CAD/CAM system where a solid model was generated to calculate mass properties such as center of gravity, weights, moments of inertia, volumes, and so on. A shaded picture was also created to assist in surface visualization. Based on this output, the model was either accepted as a final design, or modified and reprocessed through the above steps.

Once the final design had been accepted, additional drafting data were added such as surface finishes, tolerances, dimensions, administrative notes, and so on. The PDD database then underwent an integrity check for duplicate entities, duplicate dimensions, missing dimensions, and adherence to design standards. This integrity check was performed automatical-

ly by the CAD/CAM system which verified the accuracy of the data and the contiguity of the shape.

The Disk Design application demonstrated that design/drafting data on an existing CAD/CAM system can be intelligently interpreted and converted to the GMAP format for exchange to other CAD/CAM systems downstream in the manufacturing process. The key element in this process was translation of the PDD model into the GMAP working form model. The IBM working form model was used in conjunction with the PDD Editor to create working form models for the downstream demonstration applications.

3.4.3.2.5 PROcess CAPabilities

The PROCAP program feeds manufacturing process capabilities back to engineering and process planning for use in intelligent tolerancing of the product. PDD from the GMAP model were specified as parameters in a search for similar part types, materials, and features. Each manufacturing operation found to match the search parameters were displayed to aid the designer in tolerancing the disk features. The display included: the tolerance specified, the method used to machine the feature, and an associated cost factor. Thus, the PROCAP program assists the designer to intelligently tolerance a part.

Unlike any other application, the PROCAP demonstration ran directly from the PDD Editor, i.e., the PROCAP system was called directly as an option from the PDD Editor. Application-specific features such as inner diameters, outer diameters, heights, and thicknesses, were built in the PDD Editor. Other information for the PROCAP system, such as material type and specs, were coupled with the PDD and communicated to the PROCAP system. Features to be toleranced were identified by the designer on a graphics screen. The interface software interrogated the GMAP model and extracted the necessary data.

3.4.3.2.6 Feature-Based N/C Machining and CMM Inspection of Disk Features

This application used form features as a basis to access related product information such as topology, geometry, tolerances, and nonshape data from the disk PDD model. This information was used to automatically generate both N/C and CMM source programs. The specific features were associated with the counterbalance weight flange of that part.

The GMAP PDD model of the disk was translated into the working form and further refined by adding nongeometric entities to the model using the PDD Editor. The final product model of the disk included: administrative, geometry, topology, form features, tolerances, and nonshape information in addition to the geometric entities.

The disk PDD model was input to, and analyzed by, the Feature-based N/C Machining and CMM Programming application software for the existence of the target form features. These features were the key, or access point, to the underlying and associated information that was required by the N/C and the CMM programming application.

The required data were then accessed, and used to create the source programs for the N/C machining and the CMM inspection of the counterbalance weight flange features. The N/C program was output in the APT source language. The CMM program was output in the DMIS source language. These output source programs were postprocessed to create target machine

control programs on the N/C machine tool and CMM, respectively. The control programs were then used to machine and inspect the counterbalance weight flange features of the turbine disk.

The GMAP disk PDD model for this demonstration was verified as having been created exactly as specified. Application monitoring proved that, for the selected checks, the MAS and N/VI were correctly transferring the attributes of accessed entities to the application data space for application use.

The source programs in APT and DMIS were shown to be comparable to the prepared target programs. They were successfully postprocessed into machine language executable programs for the target N/C and CMM machine tools. The postprocessed machine language programs were then executed at their respective machine tools without error.

3.4.3.2.7 Disk Forging

This application focused on supplier base integration between Pratt & Whitney and Wyman-Gordon Company of Worcester, Massachusetts. Wyman-Gordon is a major supplier of disk forgings.

The subject of the demonstration was a Supplier's Report of Nonconformance (SRON), typically used by suppliers to report nonconformances. Pratt & Whitney used this SRON to disposition a nonconforming forging and to evaluate machining set-up changes required for final part shape machining. SRONs contain a variety of business technical data which are closely associated with PDD.

A typical forging SRON consists of a standard form, as shown in Figure 3-36, along with an attached diagram of a disk cross-sectional profile, shown in Figure 3-37. As part of the demonstration, Wyman-Gordon and Pratt & Whitney agreed to the specific content of a representative SRON which included:

- Representative business data elements from the SRON form
- Geometry, including forged shape, finished shape and banded shape
- Datums, tolerances, and features.

Wyman-Gordon constructed a sample disk part model on their VAX-based ANVIL CAD/CAM system. The model was then modified to contain some nonconforming characteristics. Business and other required technical data were added to the ANVIL part file using available ANVIL entities, such as text, in conjunction with level assignments. The technical data, typical of the dispositioning process, included administrative information, geometry, forged shape, finished shape, and features.

The primary objective of this application was to demonstrate the feedback of process data closely related to the product definition from a downstream life cycle function within a supplier's facility to the contractor. A secondary test objective was to verify data exchange across the dissimilar hardware platforms employed between the contractor and the supplier.

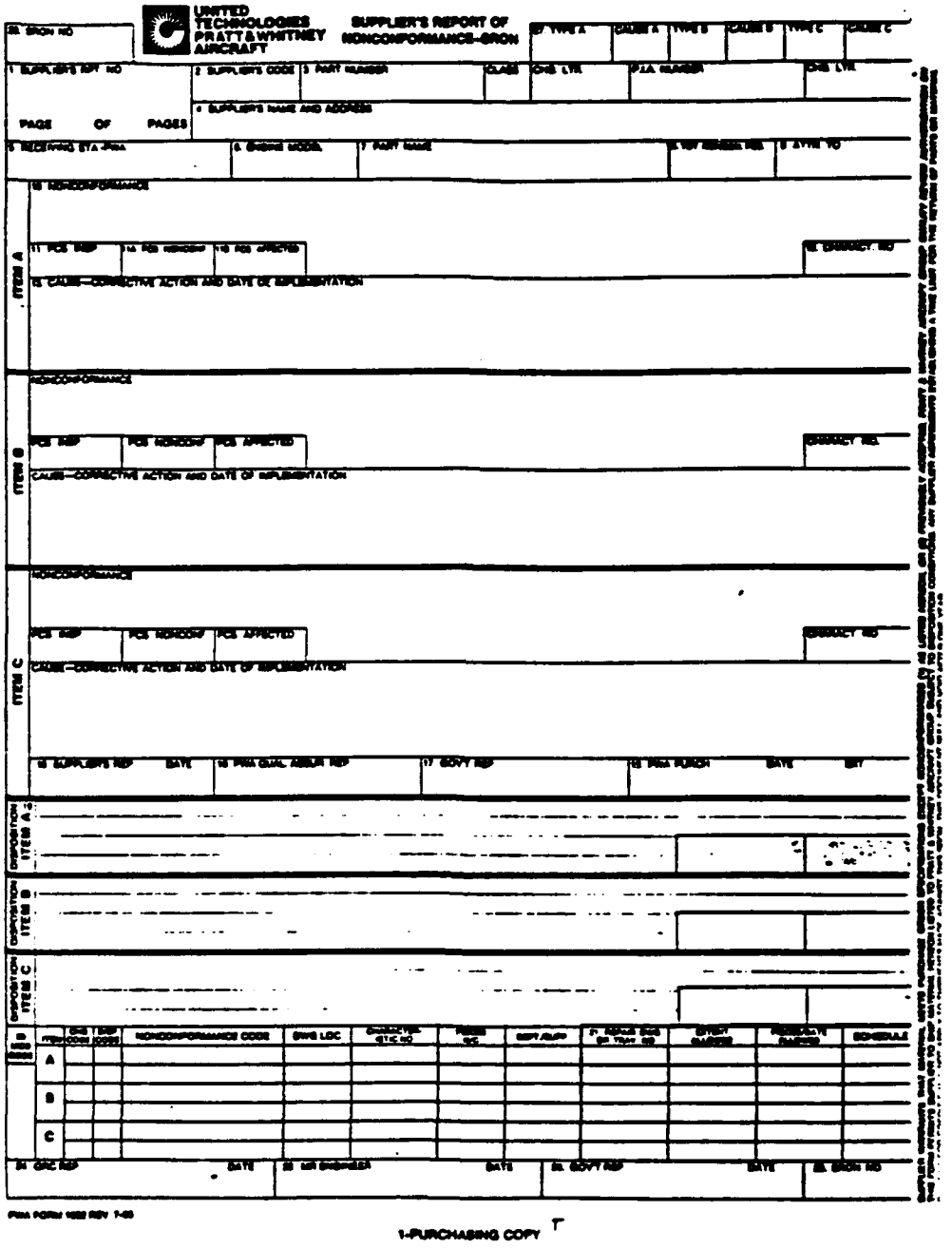


Figure 3-36. SRON Form

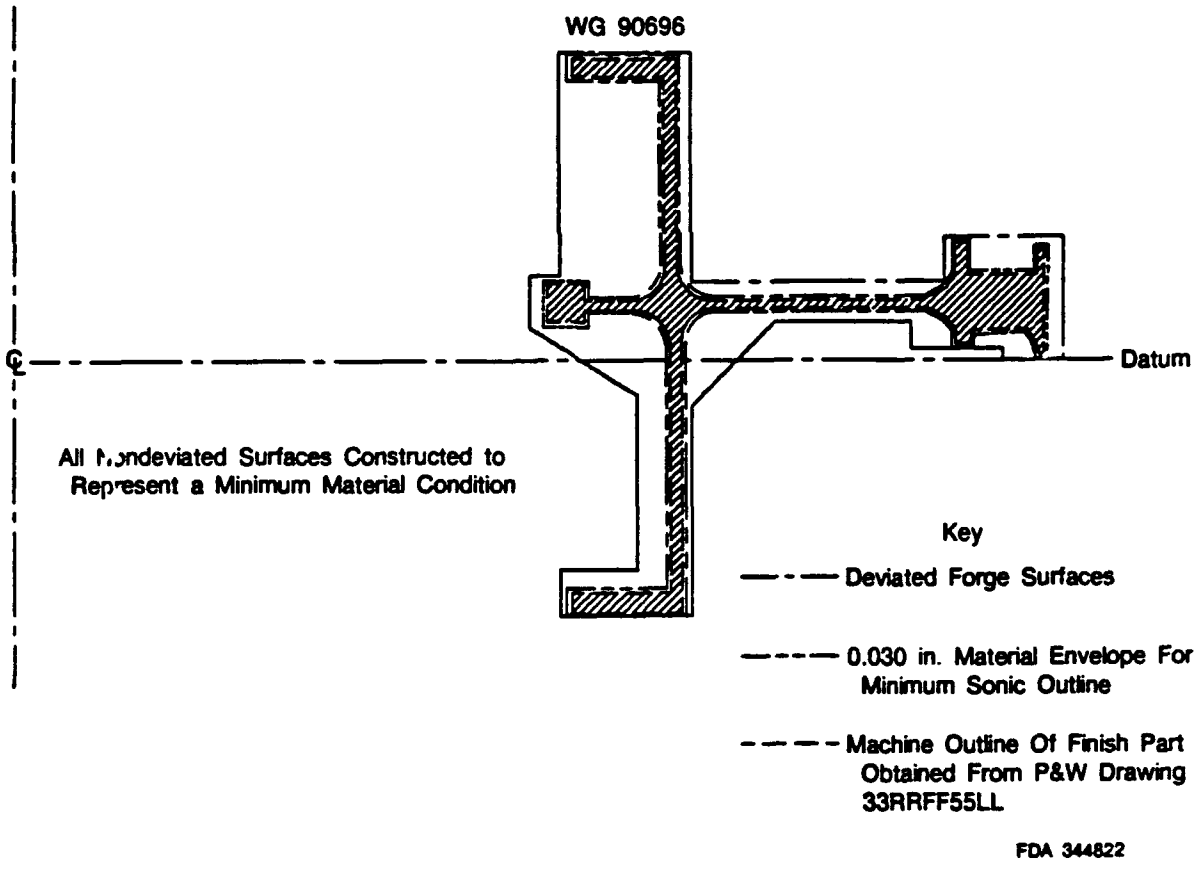


Figure 3-37. SRON Diagram of a Disk Profile

The completed SRON/product definition model was translated from the ANVIL database to exchange format using GMAP system component software and transmitted to Pratt & Whitney. Pratt & Whitney converted the exchange format to a working form model using the System Translator. This model was next translated to a representation used by Pratt & Whitney's prototype dispositioning software.

Testing of each component showed successful transfer of the disk PDD model between the supplier and Pratt & Whitney using the GMAP system software. The application translator provided the correct transfer of model entities to the native representation used by the dispositioning software.

3.4.3.2.8 GMAP-to-RFC Interface

The RFC Interface reads an exchange format file that describes a turbine engine disk, and produces one or more Unigraphics parts that are to be used in the RFC system for generating scan plans that drive disk inspection operations. The exchange format file is read and put into the working form by the GMAP System Translator's postprocessor. The RFC Interface converts the working form into one or more Unigraphics parts and flaw criteria limits file. The RFC

Interface software can be run interactively from a nongraphics terminal, or a graphics terminal emulating a nongraphics terminal, or as a batch process.

Testing was performed to verify the interface's function and quality in same three areas as the IBIS Interface: accuracy, data structure, destination.

RFC Interface testing was completed at two locations. The first three levels of testing, (module, program, and acceptance) were performed at MCAIR facilities in St. Louis, Missouri.

System Integration level testing was performed at the Systems Research Laboratories facilities in Dayton, Ohio. Systems Research Laboratories used the Unigraphics parts produced by the RFC Interface to generate the scan plan and to inspect the demonstration part.

The RFC Interface passed all specified tests and has proven its benefit to the inspection plan generation process.

3.4.3.2.9 Boss Inspection

The Engine Case Boss Inspection application was jointly conducted by Pratt & Whitney and the Department of Mechanical Engineering at RPI, in Troy, New York. The primary objective of the boss programming demonstration was to show GMAP support of more typical industrial parts than turbine blades and disks. The demonstration part was the plumbing attachment boss from a turbine engine diffuser case. The boss had shape and tolerance constraints typical of a broad range of mechanical parts.

A geometric model of a plumbing attachment boss on a diffuser case, similar to that shown in Figure 3-38, was created at Pratt & Whitney using a BREP solids modeler.

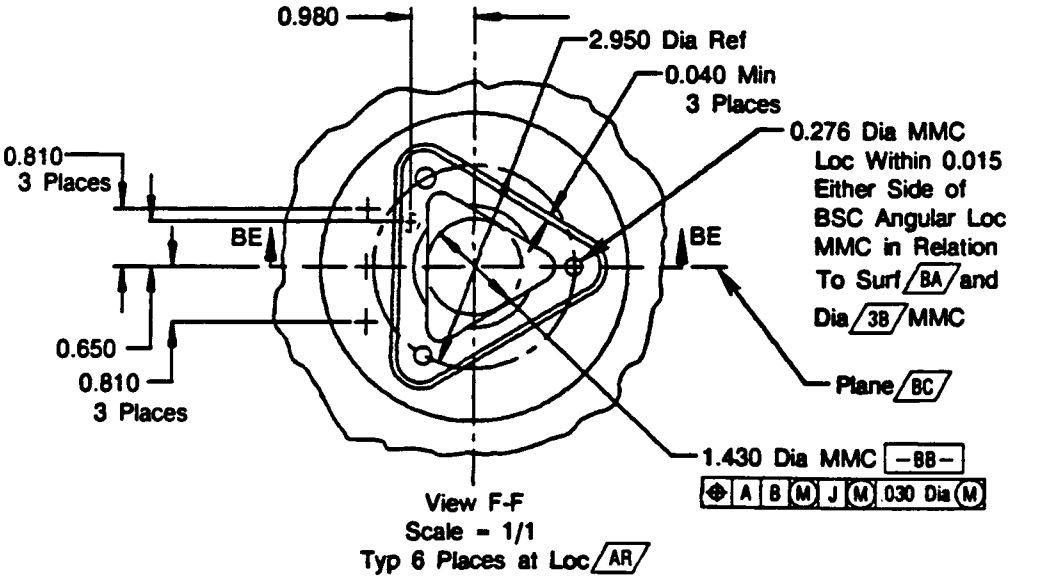


Figure 3-38. Sample Boss Part

A PDD model of the boss was created as described in 3.4.2.10. Then, an exchange file of the boss PDD model was created using the System Translator. The System Translator encoded the PDD entities into the exchange file sequential format. A magnetic tape of the exchange file was produced and transmitted to the RPI computer system.

RPI created an inspection plan for the boss detail in the DMIS language syntax. A DMIS postprocessor supplied by DEA was used to postprocess the DMIS program into the CMM's language. Finally, the part program for the boss detail was run on the DEA CMM at Pratt & Whitney. The GMAP system software worked extremely well in support of data exchange and access.

3.4.3.2.10 Boss N/C Programming

The Case Boss N/C Programming application was jointly conducted by Pratt & Whitney, Automation Technology Products, and Ingersoll Milling Machine Company. This demonstration used GMAP components to build and transfer a product model of a plumbing attachment boss. The starting point for the demonstration was a model of the boss defined in the Express language. Data in the model were gathered from an engine blueprint. The model was subsequently used to generate and verify N/C programs for machining the boss.

Two aspects of GMAP were evaluated in this demonstration: GMAP software and the GMAP schema. The GMAP software components tested were the PDD Editor, the System Translator, and the MAS. The PDD Editor created the product model of the case boss. The System Translator converted the working form model to an exchange file, and converted the exchange file back to working form. The MAS extracted the product data from the working form for conversion to the application's internal format.

The procedure was a success: the GMAP schema's representation covered all product data needed for automated N/C generation, and the GMAP software facilitated effective creation of the boss product model and communication of the product definition data to the application.

3.4.3.2.11 Display Query VAX Working Form

The Display Query system was an application developed by MCAIR on the PDDI program to verify data transfer of a sheet metal rib model between two different computer systems. This system used graphics display and user query to verify that complete PDD were transferred from the IBM part model database to the VAX working form. It interacted directly with the working form on the VAX using the MAS.

The primary objective of this demonstration was to verify that the MAS and System Translator, enhanced for GMAP, operated in conjunction with the original demonstration software and the PDDI schema model of the Sheet Metal Rib.

The new Version 5 translator was used in this redemonstration. The translation portion of the demonstration was successfully completed in four minutes compared to one hour in the original PDDI demonstration.

Correlation of the displayed sheet metal rib flat pattern with the wireframe part was established by visual comparison of general profiles and features, showing that the original functionality and integrity of the PDDI software had been maintained.

3.4.3.2.12 Classification and Coding

The PDDI Classification and Coding System was another application developed by MCAIR to semi-automatically generate the complete part class code associated with a part. A portion of this code was automatically generated from the interrogation of particular entities within the model, with the remainder of the positions created by a process planner via interactive menus.

The primary objective of this demonstration was the same as that of the Display Query demonstration: to verify that the enhanced MAS and System Translator operated in conjunction with the original demonstration software and the PDDI schema model of the sheet metal rib.

Correlation of the flat pattern with the wire frame part was established by visual comparison of general profiles and features and by light pen interrogation of hole sizes and positions.

This demonstration showed the ability of the GMAP/PDDI system to support product definitions of parts other than GMAP schema based blades and disks.

3.4.4 Produce Manuals

The System Components Operator's Manual (CI OM560240001U), the Schema Manager User's Manual (CI UM560240011U), the System Translator User's Manual (CI UM560240021U), the Model Access Software User Manual (CI 560240031U), and the PDD Editor User's Manual (CI 560240041U) were prepared to document the installation and use of the GMAP software.

The System Components Operator's Manual was validated by a MCAIR engineering employee with no previous experience with GMAP. The employee was given a copy of the Operator's Manual and tapes of the GMAP software (IBM and VAX versions) to be installed on respective equipment. The software was successfully loaded on an IBM 370 mainframe (MVS OS/VS2) and on a DEC/VAX 11/780 computer by following the procedures in the Operator's Manual. The installation procedures were modified in a few areas for clarification. These modifications were reflected in the Operators Manual.

The MAS User's Manual was validated through extensive use during enhancement, testing, and familiarization phases of the GMAP by various personnel at MCAIR, Pratt & Whitney and at ITI. N/VI sections of the manual were used at MCAIR during familiarization and testing.

The Schema Manager User's Manual and the PDD Editor User's Manual were validated during use in the testing phases of the software. The System Translator User's Manual was validated during testing of the Phase 5 System Translator.

3.5 Task 5 — Implement, Maintain, and Demonstrate GMAP

Task 5 included four Subtasks:

5.1 Implement GMAP
5.2 Maintain GMAP
5.3 Project Performance and Benefits Analysis
5.4 Demonstrate GMAP.

Subtask 5.1 demonstrated the effectiveness of the GMAP system through implementation in contractor, customer, and outside supplier computer systems. Subtask 5.2 provided modifications to the GMAP system during testing as required. Subtask 5.3 identified benefits from implementing GMAP in product life cycle applications. Under Subtask 5.4, several videotapes were produced to demonstrate the GMAP system performance.

3.5.1 Implement GMAP (Subtask 5.1)

The GMAP system software was installed at MCAIR facilities to test the components as part of the development process. For example, the Schema Manager and MAS were installed on MCAIR's IBM equipment in St. Louis for testing in the PDDI program. In addition, MCAIR installed the N/VI and the System Translator on its equipment during the GMAP effort. These activities were described in the both the System Test Plan and the System Test Report.

Additional implementations of GMAP occurred as part of the application demonstrations. MCAIR redemonstrated applications performed under the PDDI program to ensure that the system component software, enhanced for GMAP, still performed as designed with parts based on PDDI schema and of less complex geometry than blades and disks. The schema flexibility of system component software was established.

The front end of the Display Query VAX redemonstration, conducted at MCAIR, required an IBM 4340 computer environment. The Display Query software leg of the demonstration was performed on the VAX 11/780 computer system. The user interacted with the Display Query Software and the Database Retrieval Software using an Evans and Sutherland PS2 Graphics Terminal.

The Classification and Coding redemonstration, also conducted at MCAIR, required an IBM 43xx computer. The user interfaced with the software and the model through a PS 300 Evans & Sutherland graphics terminal.

3.5.1.1 Pratt & Whitney Implementations

The Parametric Cooled Turbine Blade demonstration took place on an IBM 5080 workstation, running on an IBM 3090-200E mainframe computer at Pratt & Whitney facilities in East Hartford, Connecticut.

The PROCAP application was developed as a prototype in the Manufacturing Division of Pratt & Whitney with programming support from the Engineering Division. The testing took place in the East Hartford, Connecticut plant. The PROCAP demonstration was performed on an IBM 5080 workstation linked to an IBM 3090 mainframe computer. The workstation

consisted of a 5080 graphics terminal and an alphanumeric screen (IBM 3179 terminal) and keyboard. The PROCAP output tables were displayed on the alphanumeric screen. The software is written in FORTRAN.

Another Pratt & Whitney implementation included the internal machining application for the Casting Tooling demonstration. An IBM working form GMAP model was fed to an application specific translator which used the MAS to convert it to an ANVIL part file. The ANVIL part file was then used for N/C programming. The target N/C system was ANVIL 4000, based on an IBM mainframe platform. Since ANVIL 4000 did not support NURB representation of free form curves and surfaces, the GMAP-supplied geometry was reconstructed by the translator through the use of a parametric evaluator.

All the tests for the Feature-Based N/C and CMM Programming application were conducted at Pratt & Whitney facilities in North Haven as well as in East Hartford, Connecticut. The PDD model created was inspected using the System Translator on an IBM mainframe under the VM operating system. The postprocessing of the APT N/C source program was performed on an IBM mainframe under the VM operating system, using the IBM APT N/C product, and the Monarch VMCRT postprocessor. The postprocessed machine language N/C program was executed on a Monarch vertical machining center with rotary table.

The CMM inspection of the casting tooling electrode was also performed on a DEA CMM machine located within Pratt & Whitney's North Haven, Connecticut manufacturing facility. The DMIS CMM source program was postprocessed on a Digital Electronics Corporation (DEC) VAX minicomputer running under the VMS operating system, using the DEA V1.0 prototype DMIS translator. The postprocessed machine language CMM program was then executed on the DEA CMM in North Haven.

The Disk Design application was performed at Pratt & Whitney's engineering facilities in West Palm Beach, Florida a using SUN-based CADDS4X workstation. A specific translator was written to translate the CADDS4X part model into the GMAP working form.

In the supplier electrode machining application, a GMAP exchange format model of the EDM electrode was transmitted to Mold Masters of Mentor, Ohio, a Pratt & Whitney casting tooling supplier. This model was translated into Mold Masters' Computervision CADDS4X system, based on a SUN/UNIX platform.

Another supplier implementation was the Disk Forging application. The demonstration consisted of model building at Pratt & Whitney, translation to the exchange format for delivery to Wyman Gordon, entry of the SRON data at Wyman Gordon, and translation to the exchange format for delivery back to Pratt & Whitney.

Postprocessing of the DMIS for the OMM inspection was performed on an OGP Intelligent Qualifier Machine at OGP's Rochester, N.Y. facility. The DMIS inspection program was prepared at Pratt & Whitney in East Hartford.

The Engine Case Boss Inspection application was jointly conducted by Pratt & Whitney and the Department of Mechanical Engineering at RPI, in Troy, New York. This involved implementing the GMAP software on the RPI IBM system.

3.5.2.1 PDD Editor

Informal testing and debugging of the PDD Editor occurred jointly between Pratt & Whitney and ITI during PDD model building. The results of the PDD Editor testing showed that all entities were created, modified, and/or maintained as per the GMAP schema specification.

While testing the individual options, it was found that all but three functioned as designed. The options with problems were: FILE MERGE and REGEN data did not work correctly, and the NETLIST options forced the user to halt program execution. These errors were corrected with the appropriate programming changes.

3.5.2.2 Casting Tooling Demonstration

The results of comparing the original source data file to the ANVIL part indicated that there was agreement within 0.00001 inch for the tip sections. However, the transition area between blade and root showed a mismatch of 0.004 inch. To locate the source of this error, the source data file was read into CAEDS, expanded, and profiles were created. When compared to the electrode, the same mismatch was found in the transition area. This indicated that the electrode model was not expanded correctly in CAEDS. Since this would not affect the integrity of the GMAP software or the results of the demonstration, no modifications were made to the model.

3.5.2.3 Disk Design Demonstration

In verifying exchange format accuracy, it was found that the exchange format definition did not address a default number of significant digits. Since the IBM mainframe and the UNIX workstation have different defaults, this created differences between exchange files created on the two different systems. This was corrected by providing consistent output between two systems. This problem did not occur when exchanging working form files.

3.5.2.4 Process Capabilities Demonstration

A working form-to-working form exchange across dissimilar systems was attempted in the PROCAP demonstration. The exchange format had to be used because of incompatibility. The problem was discovered during a parallelism check of a line bound on one end by an end point of an arc. The check failed. The precision of real numbers on the SUN were incompatible with the IBM.

3.5.2.5 Disk Forging Demonstration

Extensive use of the GMAP note entity was made to represent the various information items contained on the SRON paper form. No specific entities exist in the GMAP schema which can capture this information directly. To distinguish between the classes of information being represented in this fashion, an ad-hoc technique was adopted that consisted of embedding a text string in the note field of the note entity to represent the unique function of each note item. Although this technique worked, it required communication between the application programmers involved in the project.

3.5.2.6 Boss N/C Programming Demonstration

Since the CIMPLEX database, from which the N/C program was generated, was a CSG system, feature evaluation order was important. For example, a protrusion from the bottom of a pocket would be obliterated if its volume were added before removal of the pocket's volume. GMAP provided the needed information via the PRIM_FEAT_BOUND/620 entity, but more than one approach was possible. As a result, the builders of the GMAP-CIMPLEX translator had to verbally communicate with the model builders to agree on a particular method for this demonstration.

GMAP's methods for referencing individual faces of form features caused difficulties when defining tolerance targets and datums. Both situations arose with the top face of the boss's flange. The geometry of the face was defined as a PLANE/363, which was a PRIM_FEAT_BND/620 for the top of the flange. Since GMAP tolerance entities can be applied to shape data but not to geometric data, the plane could not be directly toleranced or used as a datum. Instead, the topology of the flange's top face was defined to provide a hook for the tolerance data. This approach required definition of forty otherwise unneeded entities. An alternative and more reasonable approach would have been to identify the plane as CONSTRUCTED_GEOMETRY/403, which could be toleranced. This approach would have entailed, for example, indicating that the plane was normal to an appropriately specified vector and contained an appropriate point. Intended usage of constructed geometry needs to be explicitly defined to ensure that modelers will use that approach over defining topology when appropriate.

The bottom point required for a BLIND_HOLE3/527 was incorrectly defined in the implemented GMAP schema as a COORDINATE2/213. As specified in the GMAP system specification, a COORDINATE3/313 was required. The implementation of the schema was corrected.

A deficiency was found in the GMAP schema's definition of the SURF_OF_REV/365. Since the sweep axis was specified by a direction only, there was no means of specifying an axis which did not cross the origin. The missing generality was provided by changing the schema definition of the axis from a VECTOR3/314 to a PT_VECTOR3/316.

3.5.2.7 Display Query VAX Working Form Redemonstration

One limitation encountered in this redemonstration was that the query function did not allow all displayed entities, or instances of entities, to be queried. Modifications to ensure full model interrogation are still required if this software is used in production. Also, interrogation of data levels was downward only. The ability to obtain "entity users" directly would improve its use as a model validation tool.

3.5.2.8 RFC Interface Demonstration

During RFC Interface testing, the UGIL_CONVERSION would randomly ABEND on a WRITEV command with a field width specifier too big for target string or negative. In the call to STR$TRIM from UGIL_CONVERSION, the third argument was the length of the trimmed string. The argument was supposed to be a word (2 bytes) but was specified as a 4 byte integer. So garbage bits in half of the word caused incorrect values. This number was used in a WRITEV statement. The solution was to use a 2 byte integer as specified in the DEC VAX RTL utilities manual instead of the 4 byte integer.

Also, routine PROCESS_APPROVAL produced a UNIGRAPHICS note with a reference to wrong engineering process approval specification. This was caused by an oversight in the design of the schema of the entities that prevented a consistent reference to the desired process_approval entity. To solve this problem, the method the routine uses to find the correct PROCESS_APPROVAL entity was revised.

In a third incident, the generic handler routine (GEN_HNDLR) would skip certain entities. The logic that controls the flow of execution was in error and caused entities that were child references for more than one entity to be ignored. The code was revised to process all entities.

3.5.2.9 IBIS Interface Demonstration

During IBIS Interface demonstration software development, generation of a shaded image display of the blade showed that there were several holes in some of the surfaces of the model. Some tangent values for the surfaces were not being computed correctly due to an error in the coded version of the algorithm used to convert from the parametric surface representation to the Coon's patch surface representation. The coded version of the algorithm was altered to allow a greater number of input values to be considered in creating the output surface representation.

3.5.3 Project Performance and Benefits Analysis (Subtask 5.3)

The GMAP system was developed to provide proof of concept for the use of geometric and nongeometric data in engineering and in downstream applications in manufacturing, inspection, and product and logistics support. The GMAP software demonstrated that it could function as an information supplier to the total life cycle applications.

The successes of the applications demonstrated across the product life cycle offered several benefits from implementing GMAP in a environment similar to that in which the demonstrations were performed.

3.5.3.1 Parametric Blade Design Application

The parametric blade design demonstration showed that it is possible to use the solid modeling technique to configure a complex geometry (cooled airfoil) design system that can provide rapid geometry definition and analysis, and a single, complete, and accurate PDD model consistent with all analysis requirements.

3.5.3.2 Supplier Electrode Machining

Significant reductions in labor and lead time were demonstrated by the direct feed and use of free-form NURB curves and surfaces supplied by GMAP. This avoided the costly and time-consuming reconstruction of geometry by the supplier associated with the current CAD feed environment. It was also expected to result in more accurate transmission and use of geometry as well as enable the use of nongeometric PDD.

3.5.3.3 Internal Electrode Machining

This application demonstrated that GMAP can be used to accurately transmit 3-D aerodynamic surface geometry between dissimilar CAD/CAM systems. The original NURB

geometry was accurately reconstructed on the ANVIL 4000 system. This capability is important to existing CAD/CAM applications.

3.5.3.4 Casting Tooling Applications

The CMM and OMM inspections verified that the electrodes produced by different suppliers are consistent. This is an important result because variation of product between suppliers was identified during the Needs Analysis phase of GMAP as a key problem in the current manufacturing of turbine blades. The result implies that GMAP type product descriptions can be used to control the geometry of aerodynamic surfaces produced by different suppliers using different CAD/CAM systems.

Successful completion of the four Casting Tooling applications demonstrated that GMAP could support complex turbine blade manufacturing and inspection applications. In addition, it demonstrated that GMAP could provide an important ingredient in the solution of a key technical problem, consistency of geometry among suppliers, identified during the manufacturing walkthroughs.

3.5.3.5 Disk Design

This demonstration showed that PDD information may be transferred between dissimilar computing systems in two ways, exchange format and working form. The exchange of PDD information using the exchange format is best used for external communications. The exchange of the working form between different applications was much faster since the System Translator was bypassed. However, due to computer hardware differences, the working form to working form exchange would most likely be used only for applications running on the same computer.

3.5.3.6 Process Capabilities

The PROCAP demonstration showed the application of the GMAP concepts and components to the feedback of manufacturing information to design. Today, a significant amount of emphasis is placed on quality designs based on manufacturing capabilities and meeting customer requirements. PROCAP prototyped the type of application that could be used to feedback information from any stage of the product life cycle.

3.5.3.7 Feature-Based N/C and CMM Programming

This demonstration showed that the provision of intelligent, data-rich product models can enable innovative life cycle functional applications. The use of form feature approaches to manufacturing operations, and the coupling of shape, tolerance, and nonshape information to the form features, could offer a powerful method of interfacing to product data information. This type of application can be expanded to deal with more diverse products, form features, and target machines in production environments. This could allow the concurrent development of machining and inspection program preparation from a single product data source.

3.5.3.8 Disk Forging

This application provided an important opportunity to demonstrate the extent to which the GMAP system can support application-specific data requirements. Such extensiveness is an important factor in the practical use of GMAP concepts in the CAD/CAM environment.

The ability to electronically transmit SRON information in a computer file was a more efficient means of evaluating nonconforming material for reclamation and disposition. The manufacturer could more efficiently evaluate alternatives for final part machining.

3.5.3.9 Case Boss Inspection

The case boss inspection demonstration showed how, through the use of complete product definition models, organized using form features and containing tolerances, inspection programming can be significantly enhanced.

3.5.3.10 Case Boss N/C Programming

The demonstration showed that GMAP can effectively represent and communicate PDD for a part more typical of industry at large than turbine blades and disks.

3.5.3.11 PDDI Redemonstrations

These demonstrations showed the ability for the GMAP system to support product definitions of parts other than GMAP schema based blades and disks.

The redemonstration of product models and demonstration software developed under the original PDDI project, show the ability to retrieve and use archived models with enhanced GMAP software (MAS, System Translator, working form, and exchange format). Since the GMAP software system was schema independent, there is potential for future use of the system with other schema based projects and/or production systems.

3.5.3.12 GMAP-to-RFC Interface

The RFC interface software reduced the amount of time and effort required to produce an inspection scan plan. In the future, it could become a key link in a fully automated inspection system or provide input for an automatic scan plan generator. This is possible because the RFC Interface translated a computer compatible 3-D part definition to the RFC system (Unigraphics database).

3.5.3.13 GMAP-to-IBIS Interface

The GMAP-to-IBIS Interface translated a computer compatible 3-D part definition to the IBIS system and reduced the amount of time and effort required to produce an inspection plan. In the future, it too could become a key link in a fully automated inspection system or provide input for an automatic inspection plan generator.

Additionally, IBIS feedback of analyzed flaw trends to engineering and manufacturing could lead to design and manufacturing improvements that would reduce flaw occurrence.

These benefits provided incentive for future effort to store the IBIS flaw data into an accessible database. Tasks required include organization of the flaw data into a coherent structure that would be compatible with the database, development of software that would extract the flaw data from the flaw history files and store it in the database, and creation of database retrieval software tailored for flaw history analysis.

3.5.4 Demonstrate GMAP (Subtask 5.4)

The demonstrations of GMAP technology at the end of the program were documented by the five following videotapes:

1. Executive Overview
2. Technical Summary
3. Blade Life Cycle
4. Disk Life Cycle
5. Plumbing Attachment Boss Demonstrations.

The Executive Overview, presented in an interview format, offered the views of various industry experts on the significance of GMAP technology. The Technical Summary videotape described the technical aspects of GMAP from an overall perspective. Videotapes 3,4 and 5 discussed the product life cycle applications that were selected to demonstrate the functionality of GMAP technology.

The following locations were visited by the filming crew to document the demonstrations:

- Pratt & Whitney, Government Engine Business (GEB), West Palm Beach, Florida
- OGP, Rochester, New York
- ATP, Campbell, California
- SA-ALC
- Mold Masters, Mentor, Ohio
- MCAIR, St. Louis, Missouri
- Ingersoll Milling Machine Company, Rockford, Illinois
- Pratt & Whitney, North Haven and East Hartford, Connecticut.

Draft versions of the "Technical Summary," "Blade Demonstration," "Disk Demonstration," and "Case Boss Demonstration," videotapes were reviewed by the IRB and the Air Force. The IRB members' concerns and their suggested modifications were incorporated by the Pratt & Whitney media groups.

Interviews with IRB members were videotaped at the sixth IRB for the "Executive Overview." Additional interviews with Mr. Gerry Shumaker, and Mr. Walter Reimann, the then current Air Force Chief of the CIM branch, were videotaped at Pratt & Whitney for use in this videotape. This videotape was delivered shortly after the end of the contract period.

3.6 Task 6 — Deliverable Reports

Task 6 was included as part of GMAP to account for documentation. A variety of technical and financial reports were produced in accordance with the Contract Data Requirements List

(DD Form 1423) and the Integrated Computer Aided Manufacturing Life Cycle Documentation Schedule. The majority of these documents were discussed in relation to the technical efforts that they support. Section 4 of this document provides abstracts of many of these documents. A brief synopsis of these documents is presented below.

3.6.1 Research and Development Status Report

This report, published monthly, was designed to keep project management informed of activity and progress toward the accomplishment of the GMAP objectives. The R&D Status Report was a brief narrative providing monthly status. It was not published every third month. The third month's activity was covered in Interim Technical Reports.

3.6.2 Interim Technical Reports (ITRs)

Interim Technical Reports were submitted to the AFWAL/MLTC for review at the end of each quarter. They provided documentation of technical information gathered during each quarterly contract period. ITRs were formatted based on Contract Work Breakdown Structure elements.

3.6.3 ICAM Life Cycle Documentation

The ICAM Documentation Standards, IDS150120000C, identify several technical documents that provide detailed information on specific aspects of the GMAP program. These Life Cycle documents are geared to the development Phases of the program. Section 4 of this document lists those documents.

3.6.4 Final Technical Report

The Final Technical Report summarizes the technical achievements of the program by Work Breakdown Structure element.

SECTION 4

REFERENCE MATERIAL

4.1 LIFE CYCLE DOCUMENTS

Although there have not been any ICAM Life Cycle documents published as volumes of this Final Technical Report, numerous Life Cycle documents produced during GMAP provide supportive and more detailed information and may be of interest. They are summarized briefly below. A sample Document Request Order Form is shown in Figure 4-1.

Scoping Document (SD) — The Scoping Document was the foundation document for the entire project effort. It documented the mutual understanding of the contractor and of the Air Force about the intent of the project. The SD also served as a basis for determining satisfactory contract completion. Objectives of the contract were established by the SD. These objectives were related to the contract work statement by defining the bounds of the required tasks. (SD560240001U)

Needs Analysis Document (NAD) — The NAD provided a record of the needs of the to-be system. It was used as an analysis tool to determine system requirements, and it was a basis for preliminary state-of-the-art technology investigation. (NAD560240001U)

The to-be system needs included improvements to functions that were partially performed, incorrectly performed, or that should have been performed. A benefit rationale in terms of cost, performance, and human factors as applicable, accompanied each need. Needs were prioritized according to benefits to be derived.

State-of-the-Art Review Document (SAD) — The SAD was used to determine the feasibility of solving requirements as they related to relative cost, schedule, and performance. This document was used to provide possible solution approaches even though actual system solutions were not yet designed. (SAD560240001U)

System Requirement Documentation (SRD) — This document presented a system requirement traceable to the needs identified in the NAD. The SRD was also used as an initial basis for generalizing project costs. (SRD560240001U)

System Specification (SS) — This document detailed the requirements of the SRD in terms of function, performance, physical and interface requirements and specific design constraints. (SS560240001U)

System Design Specification (SDS) — The SDS was the transition document from overall system requirements to overall system design. It formed the foundation for the remainder of the development process. (SDS560240001U)

Development Specification (DS) — This document decomposed specific manageable entities called configuration items (CIs) to a level that enabled detailed design. It described the functions, performance, environment, interfaces, and design requirements for each CI. There was a DS for the IBIS interface and a DS for the RFC interface in the GMAP project. (IBIS DS560240021U; RFC DS560240011U)

Product Specification (PS) — A PS was produced for each Development Specification: a version for the as-designed PS and a version for the as-built PS. The PS included descriptions of the structure, functions, language, database requirements, interfaces, and quality assurance provisions. The as-built PS included all of the changes made to the as-designed PS throughout the remainder of the project life cycles. (IBIS PS560240021U; RFC PS560240011U)

System Test Plan (STP) — The STP described concepts, criteria or standards, tools, and strategies for testing the overall system. Written at the system level, it addressed each requirement identified in the SS. (STP560240001U)

System Test Report (STR) — This document described the tests conducted and the methods used in analyzing test results. The STR also presented system capabilities and deficiencies for review. The status of the system in light of the test results was evaluated. (STR560240001U)

Unit Test Plan (UTP) — A Unit Test Plan was written for both IBIS and RFC and was traceable to each requirement as stated in the DS. It assured that the performance objectives stated in the DS were adequately validated. (IBIS UTP560240021U; RFC UTP560240011U)

Unit Test Report (UTR) — The UTR described the tests conducted on IBIS and RFC, the results, the method used in analyzing test results, the capabilities and deficiencies for review, and evaluated the status of the Interface in light of the test results. (IBIS UTR560240021U; RFC UTR560240011U)

Applications Manuals — Applications manuals included appropriate user and operator manuals. User Manuals (UM) were the primary reference for users, who may have had a wide range of technical sophistication and experience. Operator Manuals (OM) described the operating system commands and characteristics so that computer operators and programming personnel could operate the software. In some cases, these manuals were combined (U/OM). They were written in a step-by-step fashion to clarify and emphasize the procedures associated with the computer programs. Those manuals produced include:

- Schema Manager User's Manual (UM560240011U)
- System Translator User's Manual (UM560240021U)
- Model Access Software with Name/Value Interface (UM560240031U)

- System Components Operator's Manual (OM560240001U)
- GMAP-to-RFC Interface User/Operator Manual (U/OM560240011U)
- GMAP-to-IBIS Interface User/Operator Manual (U/OM560240021U)
- PDD Editor User/Operator Manual (U/OM560240031U)

GMAP Technical Transfer Documents (TTD) — There were three TTDs. The Demonstration Model Description document described the PDD of the GMAP demonstration models. It documented the entities and attributes that comprised the demonstration models and gave a brief description of each demonstration. The document was a guide to build the models in geometric modelers and the PDD Editor. (TTD560240001U) The Product Information Exchange System (PIES) document described the operation of the user interface to the GMAP software called PIES. PIES helps a user access/store/query/verify data from a PDES format file. (TTD560240002U) The Functional Requirements of Product Modeler document (TTD560240002U) built upon the work described in the Minimum Requirements of a Product Modeler work appended to the SRD.

Specification Change Notice (SCN) — The SCN was used to add an addendum to the System Components Operators Manual describing installation of the PDD Editor on additional platforms. (SCN-1)

Manufacturing Methods Report (MMR) — This PDDI document provided preliminary benefits analyses (MMR560240001U) of the GMAP project and a plan for tracking benefits. (MMR560240002U)

Final Technical Report (FTR) — This document provided a comprehensive review of the GMAP project and its accomplishments. (FTR56020001U)

SUBMIT DOCUMENT REQUESTS TO:

AFWAL/MLTC
ICAM Program Library
Wright-Patterson AFB, OH 45433

DOCUMENT CONFIGURATION ITEM NUMBER	TITLE OF DOCUMENT	INDICATE ( ) DOCUMENT REQUESTED

PLEASE PRINT

NAME: _____ MAIL CODE: _____

TITLE: _____

DEPARTMENT: _____

COMPANY: _____

STREET OR P.O. BOX: _____

CITY: _____ STATE: _____ ZIP: _____

REQUIREMENT FOR DOCUMENT

Document(s) requested for the purpose of (intended use and program/project application must be provided):

_____

_____

_____

_____

Documents generated under the contract contain controlled distribution and export control clauses.

I am a U.S. citizen, I am employed by a U.S. organization/company and am aware that the use of these Air Force documents must comply with:

U.S. EXPORT CONTROL LAWS

This document contains information for manufacturing or using munitions of war. Export of the information contained herein, or release to foreign nationals within the United States, without first obtaining an export license, is a violation of the International Traffic in Arms Regulations. Such violation is subject to a penalty of up to 2 years imprisonment and a fine of $100,000 under 22 USC 2778.

Signature: _____ Date: _____

Telephone No.: _____

FD386296

Figure 4-1. Document Request Order Form

R30602/6

4.2 INTERIM TECHNICAL REPORTS

Each Interim Technical Report (ITR) encompassed the work associated with a specified reporting period. They provided a brief summary of the overall project including pertinent observations; nature of technical problems; positive, as well as negative, results; and design criteria established through the reporting period.

The body of each ITR consisted of the sections described below.

- **Section 1: Introduction** — This section described the project as a whole and its objectives. It listed the tasks and subtasks that comprised the project. It was generic in nature and did not change from one ITR to another.

- **Section 2: Executive Summary** — This section consisted of three subparagraphs as follows:

  2.1 Synopsis of the work done prior to the current reporting period which has been covered in previous ITRs.

  2.2 Outline of the material contained in the ITR.

  2.3 Outline of the goals expected to be accomplished during the next reporting period.

- **Section 3: Project Accomplishments for the Reporting Period** — This section was organized in serial order by Work Breakdown Structure task and subtask that were worked on during the reporting period. Those tasks and subtasks not officially worked on were not listed.

- **Section 4: Reference Documents** — This section contained two items:

  4.1 List of Previous Interim Reports Showing Document Number and Providing Order Blanks.

  4.2 Abstracts of Approved Life Cycle Documents Produced to Date with Ordering Information and Order Blanks.

Following is a list of Interim Technical Reports produced during GMAP.

1. Interim Technical Report No. 1 (ITR560240001U)
   "Geometric Modeling Applications Interface Program" February 1986
   (Period 1 August 1985 - 31 October 1985).

2. Interim Technical Report No. 2 (ITR560240002U)
   "Geometric Modeling Applications Interface Program" May 1986
   (Period 1 November 1985 - 31 January 1986).

3. Interim Technical Report No. 3 (ITR560240003U)
   "Geometric Modeling Applications Interface Program" August 1986
   (Period 1 February 1986 - 30 April 1986).

4. Interim Technical Report No. 4 (ITR560240004U)
"Geometric Modeling Applications Interface Program" November 1986
(Period 1 May 1986 - 31 July 1986).

5. Interim Technical Report No. 5 (ITR560240005U)
"Geometric Modeling Applications Interface Program" January 1987
(Period 1 August 1986 - 31 October 1986).

6. Interim Technical Report No. 6 (ITR560240006U)
"Geometric Modeling Applications Interface Program" April 1987
(Period 1 November 1986 - 31 January 1987).

7. Interim Technical Report No. 7 (ITR560240007U)
"Geometric Modeling Applications Interface Program" August 1987
(Period 1 February 1987 - 30 April 1987).

8. Interim Technical Report No. 8 (ITR560240008U)
"Geometric Modeling Applications Interface Program" December 1987
(Period 1 May 1987 - 31 July 1987).

9. Interim Technical Report No. 9 (ITR560240009U)
"Geometric Modeling Applications Interface Program" March 1988
(Period 1 August 1987 - 31 October 1987).

10. Interim Technical Report No. 10 (ITR560240010U)
"Geometric Modeling Applications Interface Program" July 1988
(Period 1 November 1987 - 31 January 1988).

11. Interim Technical Report No. 11 (ITR560240011U)
"Geometric Modeling Applications Interface Program" July 1988
(Period 1 February 1988 - 30 April 1988).

12. Interim Technical Report No. 12 (ITR560240012U)
"Geometric Modeling Applications Interface Program" October 1988
(Period 1 May 1988 - 31 July 1988).

13. Interim Technical Report No. 13 (ITR560240013U)
"Geometric Modeling Applications Interface Program" January 1989
(Period 1 August 1988 - 31 October 1988).

14. Interim Technical Report No. 14 (ITR560240014U)
"Geometric Modeling Applications Interface Program" June 1989
(Period 1 November 1988 - 31 January 1989).

4.3 VIDEO TAPES

The demonstrations of GMAP technology at the end of the program resulted in the five following videotapes:

1. Executive Overview,
2. Technical Summary,
3. Blade Life Cycle,
4. Disk Life Cycle,
5. Plumbing Attachment Boss Demonstrations.

The Executive Overview, presented in an interview format, offered the views of various industry experts on the significance of GMAP technology. The Technical Summary videotape described the technical aspects of GMAP from an overall perspective. Videotapes 3, 4 and 5 discussed the product life cycle applications that were selected to demonstrate the functionality of GMAP technology.

4.4 TECHNICAL PAPERS

Below is a list of technical papers produced by GMAP personnel during the program.

Identification of Product Definition Data in a Manufacturing Enterprise — A Case Study. R. Lessard, United Technologies Research Center and R. Disa, Pratt & Whitney, March 1986.

Use of Product Models in a CIM Environment, D. Koziol Emmerson and K. Perlotto, Pratt & Whitney, March 1987.

Technical Issues in Product Data Transfer, Richard Lopatka, Pratt & Whitney, September 1987.

Implementation of GMAP Technologies for Logistic Support Applications, Donald L. Deptowicz, Pratt & Whitney, January 1988.

Barriers to PDES Approval, Anthony Day, Sikorsky, and Richard Lopatka, Pratt & Whitney, April 1988.

PDD: Implementation Issues, Diane Emmerson and Priscilla Blasko, United Technologies Corporation, Proceedings of AUTOFACT '88, October 1988.

Geometric Modeling Applications Interface Program: A Prototype for Active File Exchange, Linda Phillips and Diane Emmerson, United Technologies Corporation, Proceedings of National Computer Graphics Association, April 1989.

4.5 COMPUTER PROGRAMS

Section 3.4.1 describes the software that was produced under GMAP and includes Table 3-23 which identifies the software versions and platforms for GMAP software use.

4.6 SOFTWARE DOCUMENTATION

See "Manuals" under Section 4.1.

4.7 DISPLAYS

A display was produced for the Industrial Modernization Incentives Program (IMIP) in December 1988. The display will also be used at the end-of-contract Government/Industry debriefing.

4.8 TERMS AND ACRONYMS

A glossary of terms frequently used in GMAP which may be included in this Final Technical Report is provided below. A list of acronyms and abbreviations used in GMAP is also included in this section.

4.8.1 Terms Used in GMAP

Accept/Reject/Incomplete Notice — A display on the cell computer that indicates the final status of the engine disk.

Accept	= Acceptable within tolerance specified by engine manufacturer
Reject	= Rejected because of flaw(s) outside the range of acceptable tolerances
Incomplete	= Part cannot be inspected

Access Software — A set of routines for creating, managing and querying an in-core Working Form model.

Angular — An angular size tolerance is used to tolerance the size of an angular feature independent of its angular location along an arc.

Application — A method of producing a specific result.

Application Request — A request initiated by an application program, either through batch or interactive processing, which will interrogate the model through the PDDI Access Software to obtain or operate on specific information regarding the model and its components or elements.

Application Requested Data — The data which fulfills the application's original request and which is in the proper format and readable by the application.

Architecture — A design or orderly arrangement.

ASCII — American Standard Code for Information Interchange.

As-Is — The present condition.

Attribute — A quality of characteristics element of any entity having a name and a value.

B-Spline — A spline defined by a control polygon, B-spline basis functions, and an associated knot vector. A Bezier curve is a special case of a B-spline; a nurb is the most general case of a B-spline.

Bezier Curve — A type of curve defined by a set of vertices called a control polygon and a set of basis functions. The basis functions are known as Bernstein polynomials. K vertices define a curve of order K-1.

Binding — Establishing specific physical references to data structures for an application program; may be performed at compile time or at run time.

Blend — A smooth, continuous transition from one surface to another.

Boundary Representation — A topology imposed on 3-D geometric entities to yield a general solid model. That model describes an object by describing its boundary area.

Body of Revolution (BOR) Representation — A topology in which an object is represented as the volume swept by a curve rotated about a line. This is a boundary representation in which the curve represents the surface area of the object.

Bounded Geometry — Geometry that has limits defined by its mathematical domain or range.

Calibration Block Parameters (Scale Factors) — Nondestructive test parameters used to adjust a specific cell. These parameters are obtained from the calibration blocks located at each cell.

Circumferential — A circumferential tolerance specifies the tolerance zone within which the average diameter of a circular feature must lie. The average diameter is the actual circumference divided by pi (3.14159). A circumferential tolerance is a specific example of a peripheral or perimeter tolerance for a general curve.

Class — A collection of entities that are alike in some manner.

CLIST — IBM Command lists.

Composite Curve — A group of curve segments that are C^0 continuous.

Compound Feature Representation — An enumerative feature representation in which at least one component is itself a feature. For example, a bolt hole circle might be represented as a list of individual hole features.

Concentricity (Generic) — A concentricity tolerance specifies a cylindrical tolerance zone within which the axis of a feature must lie, where the axis of the zone coincides with the axis of the datum.

Conceptual Schema — Formally specified global view that is processing independent, covering information requirements and formulation of independent information structures. A neutral view of data, usually represented in terms of entities and relations.

Conic — A quadratic curve represented in the most general case by the equation:

$$Ax^2 + Bxy + Cy_2 + Dx + Ey + F = 0.$$

A conic may be a circle, line, ellipse, parabola, or a hyperbola depending on the coefficients, A, B, C, D, E, and F.

Constraints (Generic) — An assertion to explicitly specify data meaning or semantics.[1]

Context-Free Grammar — The syntax of the language gives a precise specification of the data without interpretation of it.

Constituent — A specific instance of an entity that is used in the definition of some other entity.

Data Dictionary — A catalog of all data elements in a design, giving their name, definition, format, source, and usage. May also include data types and value limits.

Defining Airfoil Sections — A planar or conical section that depicts an airfoil profile. Defining airfoil sections are those that meet aerodynamic requirements. Other intermediate sections are added for Manufacturing purposes.

Dimension — A part dimension is a quantifiable value expressing size, form, or location.

Domain — The set of values permissible in a given context.

Dynamic Allocation — The allocation (and de-allocation) of memory resources as required by the application. The opposite is static allocation where a fixed size segment of memory is available to the application.

Eddy Current Cell — Hardware used to perform an Eddy current inspection operation (surface flaws).

Eddy Current Inspection — An inspection method used to detect internal potential flaws on a disk. It is based on the principle of sending electromagnetic signals to a target area on a part and detecting/interpreting reflection (Eddy current) from the target.

Eddy Current Scan Plan — An interpreter code program controlling the Eddy current inspection of a particular geometry.

Eddy Current/Ultrasonic Flaw Data Printout — A printout containing size and location information about specific flaw(s) (both critical and noncritical) associated with a particular part.

Entity — A description of a person, place, or thing, about which information is kept.

External Reference — A reference to some quantity of data that exists somewhere outside the scope of the immediate body of information.

[1] T. J. Teorey and J. P. Fry, Design of Database Structures, 1st edition, Prentice-Hall, Inc., Englewood Cliffs, N.J., p. 463.

Feature — A part feature in the dimensioning and tolerancing context is a feature in the sense of ANSI Y14.5M, that is, a physical component portion of a part, such as a surface, hole, slot, and so on, that is used in a tolerancing situation. In the dimensioning and tolerancing context, a feature consists of individual or groups of basic shape elements used to define the physical shape of an item. This general dimensioning and tolerancing use of features is to be distinguished from Features. The word "features" alone implies dimensioning and tolerancing features. The term "form feature" is described below.

Feature Pattern — A geometric pattern of occurrences of similar form features, for example, a circular pattern of scallops, a rectangular array of holes.

Feature Representation (Generic) — A description of a form feature within the context of a geometric model.

Feature Type — A name applied to a form feature that is suggestive of its shape and size, for example, hole, slot, web.

Feature of Size (Generic) — A feature of size provides a geometric location capable of being referenced for use with datums and tolerances. A feature of size can be a GMAP feature, or other referenceable shape elements of a part model that are symmetric about a point, line, plane, axis, curve, and so on. When a feature of size is used in a relationship with a tolerance or datum, its feature of symmetry is the implied reference.

Flat Pattern Representation (Extrusion Representation) — A topology in which an object is represented as the volume swept by a planar polygon moving in a direction normal to its plane. The polygon may have internal polygon represent the surface area of the object.

Flaw Characteristics — Location, length, width, depth, and nondestructive test parameters associated with a specific flaw.

Flaw Data Packet — Packet containing nonevaluated flaw data. Note that the packet can contain zero flaws.

Flaw Orientation — The direction of the major characteristic of the flaw with respect of the part coordinate system. (See the notes section at the end of this glossary.)

Flaw Suspect Location — The coordinate location of a possible flaw detected during a survey mode inspection (six-axis position of ultrasonic cell, seven-axis position of Eddy current cell).

Form Feature — A portion of a part's geometry that is useful to regard as an entity. In a boundary representation context, this is a subset of the part's surface area.

Form Tolerance — Form tolerances are used to control the form of model features. A form tolerance specifies the amount that an actual features form may vary from nominal. Form tolerance include straightness tolerance, flatness tolerance, roundness/circularity tolerance, cylindricity tolerance, perpendicularity tolerance, parallelism tolerance, angularity tolerance, profile-of-a-line tolerance, profile-of-a-surface tolerance, circular-runout tolerance, true-direction tolerance, and mismatch tolerance.

Functionality — (1) To show that the configuration item has fulfilled the specified requirements. (2) The receiving and sending systems can operate on the entity in the same manner with the same results within a pre-defined tolerance.

Function Modeling — A description of a system in terms of a hierarchy of functions or activities, each level decomposing higher ones into greater detail. Functions are named by verbs; nouns related are declared as inputs, controls, outputs, and mechanisms.

Geometric Element (Generic) — An instance of a geometric entity.

Geometric Group — A group of geometric entities with a name.

Geometric Model — A part description in terms of its underlying geometric elements. The model may be a wireframe, surface, or solid model.

Geometric Pattern — A circular or rectangular pattern of geometric entities.

Group Technology Code — An alphanumeric string identifying significant characteristics of a product, enabling group technology applications. Also known as Part Classification Code.

Include File — PASCAL source code from another file or library included on the compilation of a PASCAL source file.

Input Data — That information which the application needs to supply in order to interrogate or operate on the model. This data may assume only these forms prescribed by the PDDI Access Software specification.

Inspection Cycle — A period for which nondestructive testing inspection requirements are defined.

Inspection Cycle Zone — An entity that is composed of a unique combination of zone and inspection cycle.

Inspection Module Operator — Refers to personnel operating RFC cell(s).

Instrument Setting Adjustments — Nondestructive testing parameter adjustments automatically accomplished via pre- and post-calibration operations. These adjustments have to be accomplished within a predetermined tolerance.

Internal Flaw — A subsurface anomaly.

Internal Flaw Major Characteristic — A vector determined by an agreed upon method.

Example (1): The vector of greatest magnitude from the centroid to a boundary of the anomaly.

Example (2): A vector representing the major axis of the minimum ellipsoidal envelope encompassing the anomaly.

Internal Flaw Tolerance — A unique combination of:

(a) Internal flaw orientation range.
(b) Serviceable internal flaw tolerance limits.
(c) Repairable internal flaw tolerance limits.

Internal Flaw Tolerance Limit — A unique combination of:

(a) Maximum diameter.
(b) Maximum depth below surface.
(c) Maximum thickness.

Interpreted Request — Input data which has been appropriately modified to conform to the PDDI Access Software's internal data representation so that it may be further processed.

Key Attribute — An attribute or combination of attributes having values that uniquely identify each entity instance.[2]

Laminates Representation (Generic) — A topology in which an object is represented as layers of flat material of known thickness.

Location Tolerance — Location tolerances specify the allowable variation in position of model features. Location tolerances include various forms of position tolerancing conventions. These are (true) position, concentricity, alignment, rectilinear location, and angular location.

Logistics Support — The function of procuring, distributing, maintaining, replacing, and repairing material in support of a delivered product.

Machine Coordinate Positions — The probe location with respect to machine coordinates.

Machine Preset Data — Machine coordinate adjustments automatically accomplished via pre- and post-calibration operations. These adjustments have to be accomplished within predetermined tolerance.

Metadata — Data about data. Defines the physical schema and record formats of the part data.

Metamodel — A body of data that defines the characteristics of a data model or structure.

Model — A collection of PDD that is transferable, displayable, accessible, and equivalent to a Part. The internal representation of the application data, as initiated and organized by the user. The model is also referred to as the Working Form.

Model Network Definition — The set of rules and definitions which outline in detail the data structure whereby higher order entities may be composed of lower order entities, or constituents, and the lower order entities may be constituents of one or more higher order entities.

[2] Integrated Computer Aided Manufacturing (ICAM) Architecture, Vol. 5, Information Modeling Manual (IDEF1), USAF Report No. AFWAL-TR-81-4023, June 1981, p. 212.

Native System — The PDD and applications in a format that is unique to the database of a CAD system.

Nondestructive Testing Parameters — Parameters used by the Eddy current and ultrasonic instruments (examples: amplitude, phase angle, gain, threshold, and so on).

Nonconstructive Feature Representation (Explicit Feature Representation) — A feature representation that at least partially depends on a declaration that a face, or portion of a face, it "in" the feature.

Nondestructive Testing Personnel — Personnel responsible for the generation of scan plans and derivation of applicable nondestructive testing instrument settings used in the scan plans.

Nonshape Data — Produce definition data that cannot be represented by shape elements.

Normal Forms — Conditions reflecting the degree of refinement and control over the relationships and entities in an information model.

Numerical Control Program (Complete and Proposed) — Set of program instructions used to generate a probe path.

Orientation Range — An envelope in which the major flaw characteristic must lie.

Parse — The process of analyzing input strings (records) to identify fields and to verify that the data has a valid format.

Part Blueprint — A blueprint provided by the engine manufacturer of a particular F100 engine disk.

Physical Schema — Internal representation of data; the computer view that includes stored record format and physical ordering of stored records.

PID File — A PID File is a copy of the Working Form filed to disk for temporary storage. The software that produces this capability (PID Code) is provided as an interim solution while a translator to the native database is in development.

Polynomial Spline — A parametric spline of order 1, 2, or 3 defined by a set of N+1 points. The spline is CX, CY, or CZ continuous and defined by coefficients such that:

$$x(i) = AX_{(i)} + BX_{(i)} * S + CX_{(i)} * S**2 + DX_{(i)} * S**3$$

$$y(i) = AY_{(i)} + BY_{(i)} * S + CY_{(i)} * S**2 + DY_{(i)} * S**3$$

$$z(i) = AZ_{(i)} + BZ_{(i)} * S + CZ_{(i)} * S**2 + DZ_{(i)} * S**3$$

and a parameter space $(T_0, T_1, \ldots T_{kn})$

where

$$T_{(i)} <= u <= T_{(i+1)}$$

$$S = u - T_{(i)}$$

Position Tolerance — A position tolerance (true position) specifies a tolerance zone within which the feature may vary in any direction.

Post-processor — A phase of the translator where data is received from the Exchange Format and is converted to the Working Form.

Pre-processor — A phase of the translator where data is taken from the Working Form and is converted to the Exchange Format.

Primitive Constructive Feature Representation (Generic) — A constructive representation that is noncompound and that does not incorporate another feature. Such a representation must consist solely of overt construction information. Representation of a through hole by centerline and diameter is an example.

Probe Blueprint — Blueprint of Eddy current probe supplied by the probe manufacturer.

Product Definition Data — Those data "explicitly representing all required concepts, attributes, and relationships" normally communicated from Design throughout Manufacturing and Logistics Support. The data include both shape and nonshape information required to fully represent a component or assembly so that it can be analyzed, manufactured, inspected, and supported. They enable downstream applications, but do not include process instructions. These data are not always finalized at the design release; the manufacturing process can also add to the product model or generate derived manufacturing product models.

Product Life Cycle — Includes design, analysis, manufacturing, inspection, and product and logistics support of a product.

Product Model — A computer representation of a product.

Product Support — The function that interprets customer requests for information and can provide the technical responses to the customer in the form of technical orders and instructions.

Proprietary Part Flaw Data — Formatted dataset containing proprietary data defining size(s), maximums, and location(s) of critical flaw(s) (dimensional and locational tolerance).

RAW.O File — A data file that uses a bi-cubic patch surface representation to define the surfaces of an airfoil.

Ready Status — Go/No-Go decision.

Relation — A logical association between entities.[3]

Remount Decision — Decision to remount an engine disk.

Replicate Feature Representation (Generic) — A description of a feature as being identical to another feature except for location. Mathematically, a replicate feature representation consists of the identification of another (necessarily constructive) feature plus a transformation.

Robot Initialization Parameters — A set of nondestructive testing parameters used to initialize the robot on an Eddy current or ultrasonic cell.

Rotational Sweep — A sweep in which the swept curve is rotated about a line (the "centerline" of the sweep).

Ruled Surface (Generic) — A surface defined by a linear blend of two curves.

Run System — The Translator subpackage which provides the communication interface between the user and the pre/Post-processors.

Run-Time Subschema — A subset of the data dictionary information used at run-time by the access software to provide field data and check data.

Scan Plan — Instructions that drive an inspection; these include inspection area geometry, ordered inspection path points, inspection probe selection, inspection path for each probe, mechanical commands that allow mechanical manipulator positioning, instrument setting, and all the variables needed for signal processing and flaw data acquisition during inspection.

Scan Plan Specifications — Standards and procedures used in creating Eddy current and ultrasonic scan plans for the RFC system.

Schema — Formal definition of information structure. See Conceptual Schema, Physical Schema, Run-time Schema.

Shape — The physical geometry of a mechanical part, as distinguished from a computer description of that geometry. Where the difference is significant, the attitude is taken that shape is nominal or basic, with shape variations of tolerances grafted thereon.

Shape Data — Include the geometric, topological description of a product along with the associated dimensional tolerances and feature descriptions.

Single Spatial Probe/Transducer Path — The starting and ending location of a single probe movement.

Size Tolerance — Size tolerances specify the allowable variation in size-of-model features, independent of location. Size tolerances include circumferential, rectilinear size, and angular size.

[3] Ibid., p. 214.

Solid Geometric Model (Shape Representation) — A computer description of shape. The description may be partial in the sense that not all aspects of part shape are indicated. For example, a body of revolution representation of a turned part may not describe the nonaxisymmetric[4] aspects of part geometry. A solid model must be complete and unambiguous in the sense that it describes a single volume in 3-D space.

Solid Modeling — The creation of an unambiguous and complete representation of the size and shape of an object.

Source Code — A computer program written in some language which is processed to produce machine code.

Spline — A piecewise polynomial of order K, having continuity up to order K-1 at the segment joints.

Squirter Blueprint — Blueprint of the squirter head that houses the ultrasonic transducer.

Subface — A subface is a bounded portion of a face. It is defined by an underlying face, exactly one periphery closed curve and zero, one, or more internal closed curves that represent cutouts or holes in the region. The internal closed curve must not touch or intersect each other or the periphery closed curve and must be entirely contained within the periphery closed curve.

Surface Flaw — A surface anomaly.

Surface Flaw Major Characteristic — A *vector determined by an agreed upon method.*

Example: A vector representing the major axis of the minimum elliptical envelope encompassing the anomaly in the plane of the surface.

Surface Flaw Tolerance — A unique combination of:

(a) Surface flaw orientation range.
(b) Serviceable surface flaw tolerance limits.
(c) Repairable surface flaw tolerance limits.

Surface Flaw Tolerance Limit — A unique combination of:

(a) Maximum length.
(b) Maximum width.
(c) Maximum depth.

Sweep Surface — Surfaces formed by extruding or revolving a planar profile in space.

Syntax — Grammar: A set of rules for forming meaningful phrases and sentences from words in a vocabulary.

[4] Ibid., p. 211.

System Computer — VAX 11/780 and supporting peripheral hardware.

System Constraints — Those hardware and software environmental constraints which will be imposed upon the PDDI Access Software that will limit its implementation and application. An example of such constraints might be the particular compiler used to compile the PDDI Access Software package.

To-Be — The future condition possible, given a proposed capability.

Tolerance (Generic) — The total amount by which something may vary. For mechanical product definition, tolerances can be shape tolerances, weight tolerances, finish tolerances and so on. In the context of GMAP, the term "tolerance" used alone implies shape tolerance. Other forms of tolerance (nonshape) are explicitly stated, for example, "finish tolerance." In a GMAP product model, tolerances occur without dimensions. As in the Product Definition Data Interface Program, model dimensions are implicit in the model geometry. Therefore, application of a tolerance implies a specific underlying dimension or geometric condition.

Topology — A data structure that assembles geometric entities (points. curves, surfaces) into a solid geometric model.

Transducer Blueprint — Blueprint of ultrasonic transducer supplied by the transducer manufacturer.

Transfer Data — The data required to make an exchange of data between systems (i.e., delimiters, record counts, record length, entity counts, numeric precision).

Translator — A software MECHANISM that is used for passing data between the Exchange Format and Working Form of the PDD.

Ultrasonic Cell — Hardware used to perform ultrasonic inspection operation (internal flaws).

Ultrasonic Inspection — An inspection method used to detect surface flaws on a disk. It uses ultrasonic waves through a stream of water to send and collect signals concerning an area targeted for inspection.

Ultrasonic Scan Plan — Interpreter code program controlling the ultrasonic inspection of a particular geometry.

Unbounded Geometry — Geometry represented parametrically, without limits, usually by coefficients to a defining equation.

Unigraphics (UG) — A computer graphics system.

User Function (UFUNC) — An interface to the UG database.

Working Form — Product definition data information in machine-dependent data formats; an a memory resident network model.

Zone — A physical area of the disk composed of zone components.

Zone Component — A subface, face, or feature that constitutes a zone or element of a zone.

4.8.2 Acronyms Used In GMAP

ADB — Application Data Block (also referred to as Attribute Data Block).
AIMS — Automated IDEF Methodology System.
ANSI — American National Standards Institute.
ANT — Abstract of New Technology.
APT — Automatically Programmed Tools.
ATP — Automation Technology Products.
BOM — Bill of Materials.
BOR — Body of Revolution.
BPI — Bits per Inch.
BREP — Boundary Representation.
CAD — Computer Aided Design.
CAE — Computer Aided Engineering.
CAEDS — Computer Aided Engineering Design System.
CALS — Computer-aided Acquisition and Logistics Support.
CAM — Computer Aided Manufacturing.
CAM-I — Computer Aided Manufacturing—International.
CAPP — Computer Aided Process Planning.
CAS — Cooled Airfoil System.
CDM — Common Data Model.
CDR — Critical Design Review.
CDT — Component Design Technology.
CFSR — Contract Fund Status Report.
CI — Configuration Item.
CIM — Computer Integrated Manufacturing.
CLIST — IBM command list.
CM — Configuration Management.
CMM — Coordinate Measuring Machine.
C/SSR — Cost/Schedule Status Report.
CWBS — Contract Work Breakdown Structure.
DBMS — Data Base Management System.
DCL — DEC Command Language.
DDL — Data Definition Language.
DEA — Digital Equipment Automation.
DEC — Digital Equipment Corporation.
DES0 — (ICAM) Architecture of Design.
DJR — Design Job Request; Drafting Job Request.
DoD — Department of Defense.
DS — Design Specification.
DSM — Design Substantiation Memo.
EBCDIC — Extended Binary Coded Decimal Interchange Code (IBM character set).
EC — Eddy Current.
ECO — Engineering Change Order.
EDM — Electrical Discharge Machining.

EF — Exchange Format.
EII — Engineering Information Index.
EMD — Engineering Master Drawing.
EPCS — Engine Product Configuration Support.
ESA — Engineering Source Approval.
ESP — Experimental Solids Proposal.
FEDD — For Early Domestic Dissemination.
FEM — Finite-Element Modeling.
FOF — Factory of the Future.
FOS — Feature of Size.
FPIM — Fluorescent Penetrant Inspection Module.
FSCM — Federal Supply Code for Manufacturers.
GE — General Electric.
GMAP — Geometric Modeling Applications Interface Program.
GSE — Ground Support Equipment.
HCF — High-Cycle Fatigue.
IBIS — Integrated Blade Inspection System.
IBM — International Business Machines.
ICAM — Integrated Computer Aided Manufacturing.
ICOM — Input/Control/Output/Mechanism.
ICS — Information Computer System.
IDEF — ICAM Definition.
IDEF0 — IDEF Function Modeling.
IDEF1 — IDEF Information Modeling.
IDEF1X — IDEF Extended Information Modeling.
IDEF2 — IDEF Dynamics Modeling.
IDSS — Integrated Decision Support System.
IEEE — Institute of Electrical and Electronics Engineers.
IEN — Internal Engineering Nocice.
IFS — Interface Specification.
IGES — Initial Graphics Exchange Specification.
IISS — Integrated Information Support System.
ILC — Improved Life Core.
IMS — Information Management System.
IPGS — (IBIS) Inspection Plan Generation System.
IRB — Industry Review Board.
IRIM — Infrared Inspection Module.
ISO — International Standards Organization.
ITA — Intelligent Task Automation.
ITI — International TechneGroup Incorporated.
ITR — Interim Technical Report.
LCF — Low-Cycle Fatigue.
MAS — Model Access Software.
MCAIR — McDonnell Douglas Corporation/McDonnell Aircraft Company.
MFG0 — (ICAM) Architecture of Manufacturing.
MRP — Materials Requirements Planning.
NAD — Needs Analysis Document.
NBS — National Bureau of Standards.
N/C — Numerical Control.

NDE	—	Nondestructive Evaluation.
NDML	—	Neutral Data Manipulation Language.
NDT	—	Nondestructive Test.
NTSB	—	National Transportation Safety Board.
NVI	—	Name/Value Interface.
OGP	—	Optical Gaging Products, Inc.
PA/QA	—	Product Assurance/Quality Assurance.
PD	—	Product Data.
PDD	—	Product Definition Data.
PDDI	—	Product Definition Data Interface Program.
PDES	—	Product Data Exchange Specification.
PDL	—	Program Design Language.
PED	—	Preliminary Engine Design.
PI	—	Principal Investigator.
PID	—	PDDI Interim Database.
PIES	—	Product Information Exchange System.
PMP/PMS	—	Program Management Plan/Project Master Schedule.
PROCAP	—	Process Capability.
PS	—	Product Specification.
RFC	—	Retirement for Cause.
RPM	—	Revolutions per Minute.
SA-ALC	—	San Antonio-Air Logistics Center.
SAD	—	State-of-the-Art Document.
SD	—	Scoping Document.
SDL	—	Source Data List.
SDS	—	System Design Specification.
SL	—	Salvage Layout.
SML	—	Source Material Log.
SOA	—	State-of-the-Art (Survey).
SOR	—	Surface of Revolution.
SPC	—	Statistical Process Control.
SPF	—	System Panel Facility.
SQA	—	Software Quality Assurance.
SQAP	—	Software Quality Assurance Plan.
SRD		System Requirements Document.
SRL	—	Systems Research Laboratories.
SS	—	System Specification.
STEP	—	Standard for the Exchange of Product Model Data.
STP	—	System Test Plan.
TCTO	—	Time Compliance Technical Order.
TD	—	Technical Data.
TDCR	—	Turbine Design Cost Reduction.
TDR	—	Tool Design Request.
TechMod	—	Technology Modernization.
TO	—	Technical Order.
TOP	—	Technical and Office Protocol.
TSO	—	Time-Sharing Option (IBM term).
UFUNC	—	User Function.
UG	—	Unigraphics.

UGFM	—	Unigraphics File Manager.
USA	—	Unified System for Airfoils.
USAF	—	United States Air Force.
UTC	—	United Technologies Corporation.
UTP	—	Unit Test Plan.
UTR	—	Unit Test Report.
UTRC	—	United Technologies Research Center.
VAX	—	Virtual Architecture Extended.
VMS	—	Virtual Memory System.
WBS	—	Work Breakdown Structure.
WF	—	Working Form.
WPAFB	—	Wright-Patterson Air Force Base.
XIM	—	X-Ray Inspection Module.

APPENDIX A

UPPER LEVEL MODEL OF RELATIONSHIPS OF LIFE CYCLE ACTIVITIES FOR TURBINE BLADES AND DISKS

The objective of creating the GMAP scoping function model was to provide an indication of the scope that GMAP has in the product life cycle of turbine blades and disks. The GMAP scoping function model was developed by interviewing key individuals familiar with jet-engine design, manufacturing, and product support. The data obtained during these interviews were then analyzed to produce an upper-level GMAP 0 model. Although sufficient data were collected through these interviews to decompose and analyze the resulting GMAP/A-0 level through several levels, only the GMAP A-0 and A0 levels are presented here.

The GMAP 0 model has been compared to the Composite View DES0 and MFG0 models. Comments are included in the supporting text to indicate where the GMAP 0 concurs with or differs from the DES0 and MFG0 models.

A node tree diagram is presented in Figure A-1. This diagram illustrates the node list and indicates which functions will be decomposed further during the detailed part modeling walk-through. GMAP is expected to have primary impact on the areas indicated.

The primary objective of A-0, Develop and Produce Engine Products (Context) is to provide engine products. A secondary objective is to provide support to the users of those engine products. The function, as shown in Figure A-2, fulfills these objectives by procuring items and then directing the personnel, material, equipment, and facilities necessary to develop and produce the engine products. This function incorporates all the engine product life cycle activities within an aircraft engine product manufacturing enterprise, Pratt & Whitney and any suppliers of material or services acting as contracted extensions of Pratt & Whitney.

This function is performed according to:

- the requirements of any contract existing between the customer and Pratt & Whitney;
- the goals and policies of Pratt & Whitney;
- any validated suggestions for improvements in the engine product arising from its use or performance.

The performance of the function is the responsibility of Pratt & Whitney in concert with its suppliers. The activities included within this function generally correspond to those within the Composite View architecture upper-level function A-1 (Develop and Produce Aerospace Product).

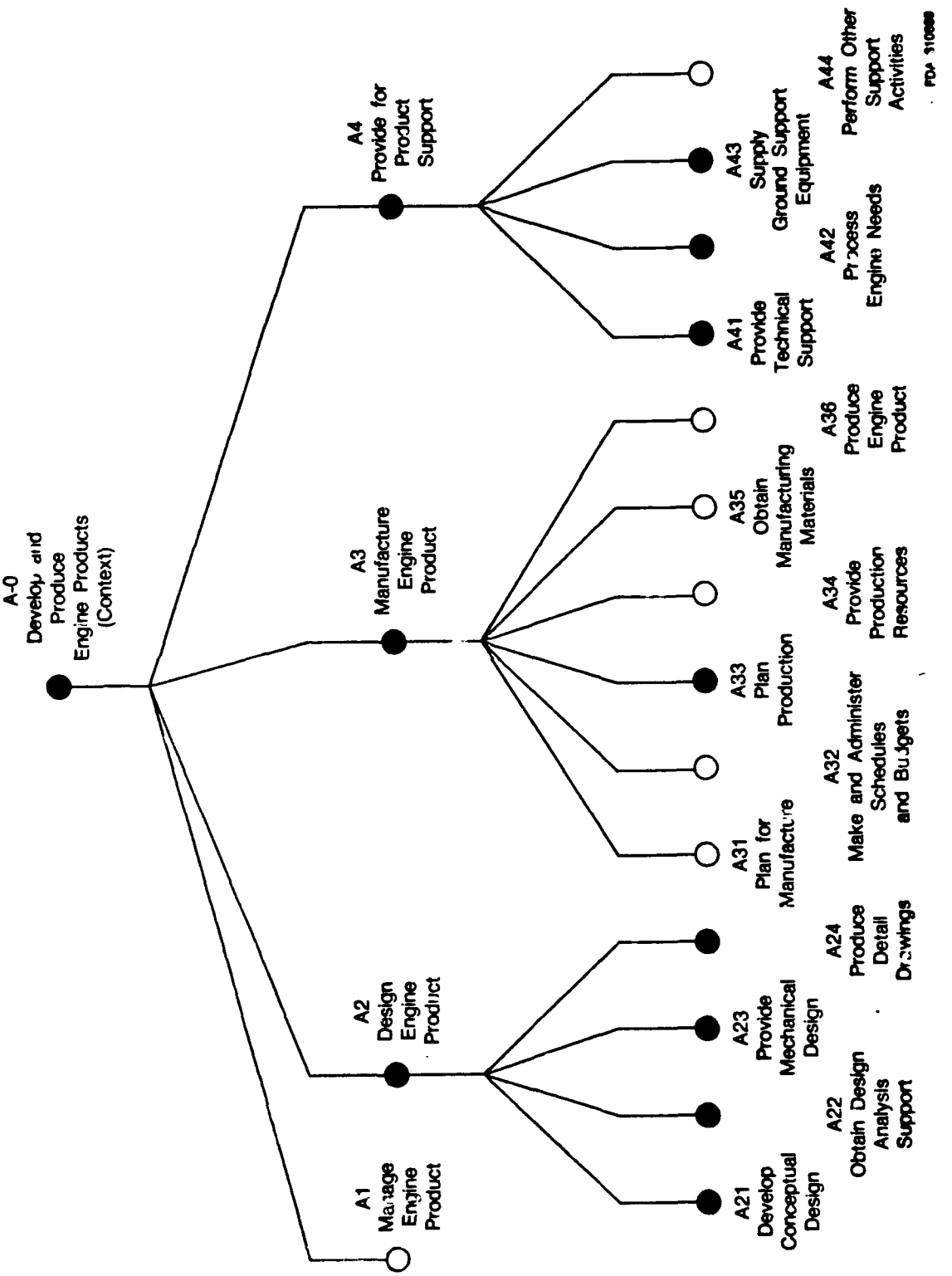


Figure A-1. GMAP Node Tree

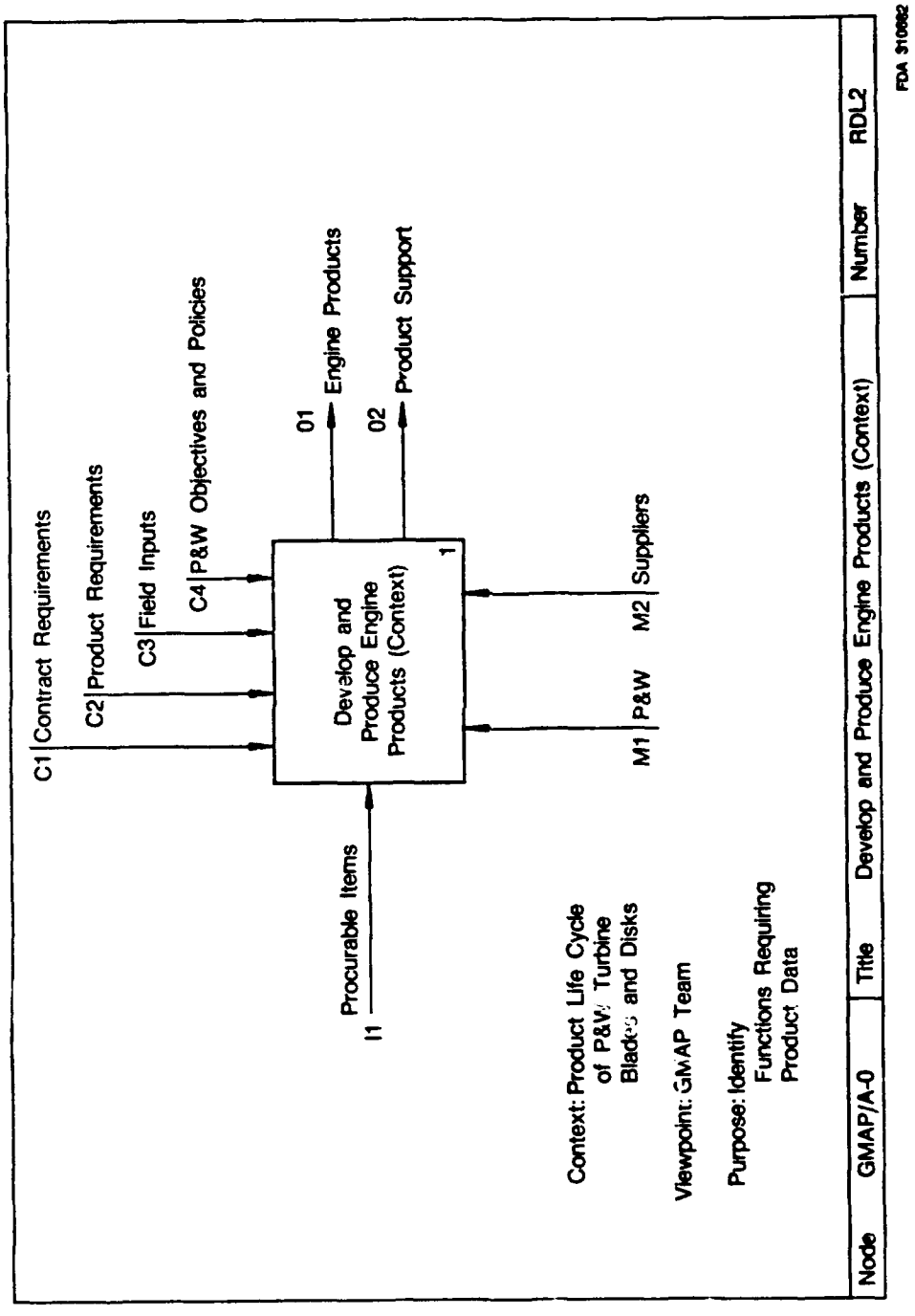


Figure A-2. A-0 — Develop and Produce Engine Products (Context)

This function model was developed to identify functions within the product life cycle for Pratt & Whitney turbine blades and disks (Context) that require product data (Purpose). Because of the numerous reviews that the model underwent prior to publication, the model reflects the consensus view of the GMAP team (Viewpoint).

The primary objective of A0 Develop and Produce Engine Products is to provide engine products. A secondary objective is to provide support to the users of those engine products. This function fulfills these objectives by:

- designing engine products;
- procuring the personnel, material, equipment, and facilities necessary to manufacture the engine products;
- providing support to the user for the engine product;
- managing the design, manufacture, and support activities.

The first three of these activities include the anticipated engine product life-cycle activities that will be impacted by GMAP.

The function is performed according to:

- the requirements of any contract existing between the customer and Pratt & Whitney;
- any validated and approved suggestion for improvement in the engine product arising from its use or performance.

The activities within this GMAP architecture upper-level A0 function generally correspond to those within the Composite View architecture upper-level function A-01 (Develop and Produce Engine Products), as shown in Figure A-3.

The first function, Manage Engine Products, is responsible for evaluating the objectives and policies of Pratt & Whitney and the requirements of the contract between the customer and Pratt & Whitney.

Once an evaluation has been accomplished, management direction is provided to control the performance of the design, manufacture, and support functions. To comply with this charter, the manage function participates in the product life cycle. In response to product requirements and suggestions, product data describing the capabilities of Pratt & Whitney engine products are reviewed by management.

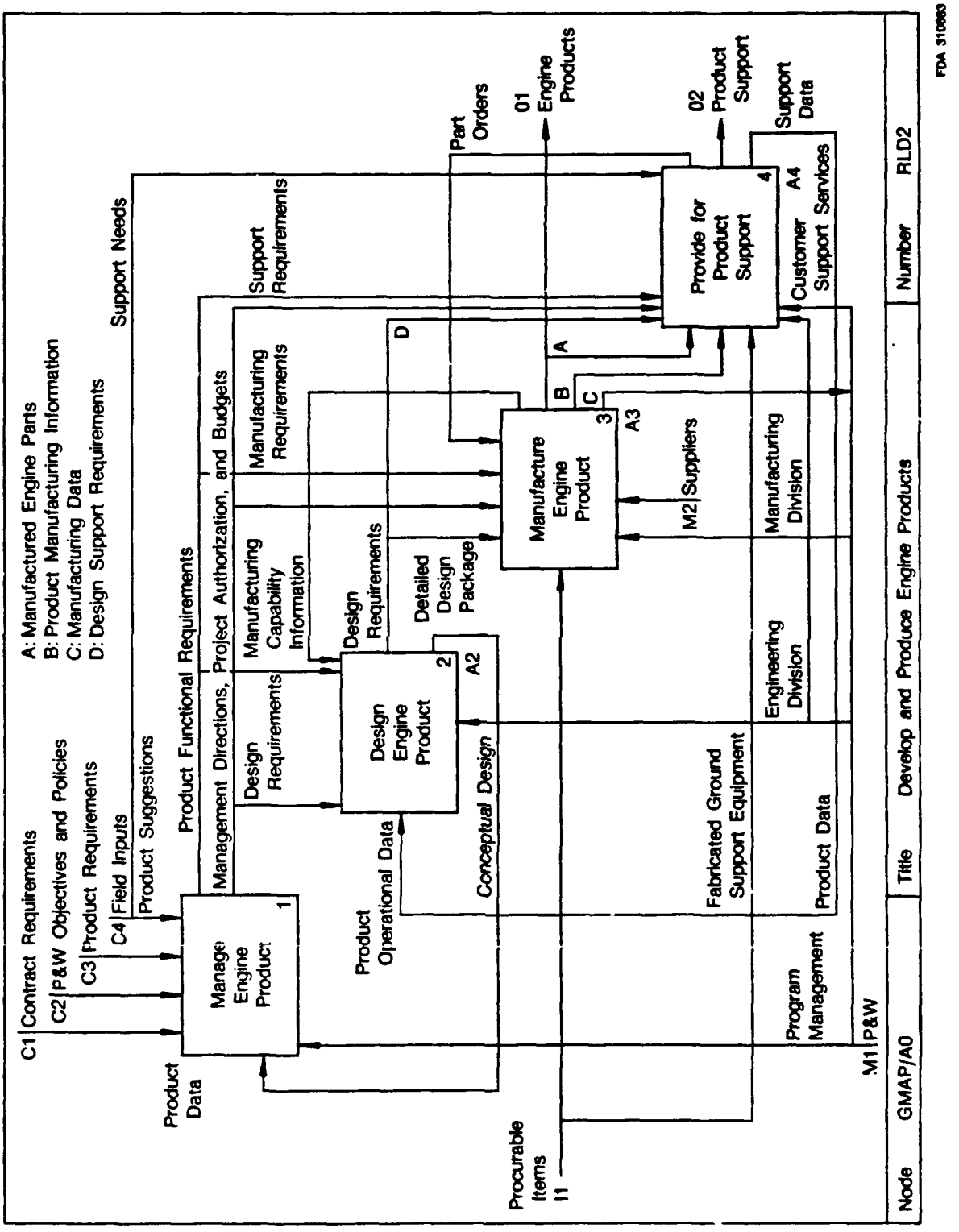


Figure A-3. A-0 — Develop and Produce Engine Products

This review results in a preliminary definition of product functional requirements, which is passed on to the design, manufacturing, and support functions. Once a conceptual design that potentially incorporates the product functional requirements for the engine product has been prepared, management will review the design and decide whether further implementation of the design concept meets Pratt & Whitney objectives and policies. If the answer is positive, a project authorization including budgetary and schedule guidelines will be produced.

The second function, Design Engine Product, is responsible for creating engine product designs of sufficient detail and accuracy that the GMAP/A3 function (Manufacture Engine Product) can use them to develop the instructions for production. The activities within the design function include:

- developing a conceptual and subsequent final design;
- producing a design layout;
- adding manufacturing data to the design layout to produce a detailed design drawing.

This function is governed by the design functional requirements, the capability of the production equipment, and management direction.

The third function, Manufacture Engine Product, is responsible for performing the activities required to plan, provision, and produce the engine product. With this function are the activities of:

- planning for manufacture;
- establishing budgets and schedules;
- creating production plans;
- providing production resources;
- procuring material;
- producing the engine products.

The primary outputs generated are those of the manufactured new engine and engine parts, manufacturing data, and product manufacturing information. Controls over the function include the product design, the manufacturing requirements, and the direction and authorizations provided by Pratt & Whitney management.

The fourth function, Provide for Product Support, is responsible for providing customer support for the engine products. Within this function are four major activities:

- providing technical support in the form of instructions relative to the engine products;
- processing customer requests for additional engine parts;
- supplying the customer with ground support equipment for use with the engine products;

- providing additional support activities, such as logistics forecasting warranty administration and incident investigations.

The conduct of these activities is guided by the support needs of the customer and to the support requirements as delineated by Pratt & Whitney management.

During the A2 — Design Engine Product activity, as shown in Figure A-4, engine product designs (in this instance turbine airfoil or disk designs) are created and provided to the GMAP/3 function (Manufacture Engine Product). Specific production instructions are generated from this input. Design activities, leading to the creation of the manufacturing input information include:

- providing analytical support studies that produce a final design;
- development of conceptual or preliminary designs for management evaluation;
- integrating the mechanical design steps to produce a design layout;
- performing the final drafting activities of adding resulting in detail drawings.

Controls over the function include the product design, the manufacturing requirements, and the direction and authorizations provided by Pratt & Whitney management.

The activities within this GMAP/A2 function generally correspond to those within the Composite View DES/A0 function (Design Product). However, a logical decomposition of the activities within Pratt & Whitney requires a four-function decomposition for the GMAP/A2 rather than the three-function decomposition applied to DES/A0.

The first function, Develop Conceptual Design, begins the product life cycle. It involves the initiation of a preliminary study based on new product functional requirements. These requirements may be either vague or specific. In either instance, however, they must be investigated and evaluated to determine the validity and extent of its impact.

The investigation will often result in the preliminary and component design groups scoping the extent of the impact and the benefits of the requirement change, and the resulting time and costs to implement the change. Product design criteria are supplied to the Component Technology groups and form the basis for the initial product design. This design will be used by management to decide whether the project should be approved. The design will also be used to provide the Component Technology groups and the Mechanical Designer with a base for beginning the detail design layout.

In the second function, Produce Final Product Design, the aerodynamic, durability, and structures groups produce a final turbine airfoil design for the mechanical design layout. The Aerodynamic group identifies candidate turbine blade shapes that meet the functional requirements, while the Durability and Structures groups address such design elements as airfoil cooling, component life, heat transfer characteristics, and stress analysis.

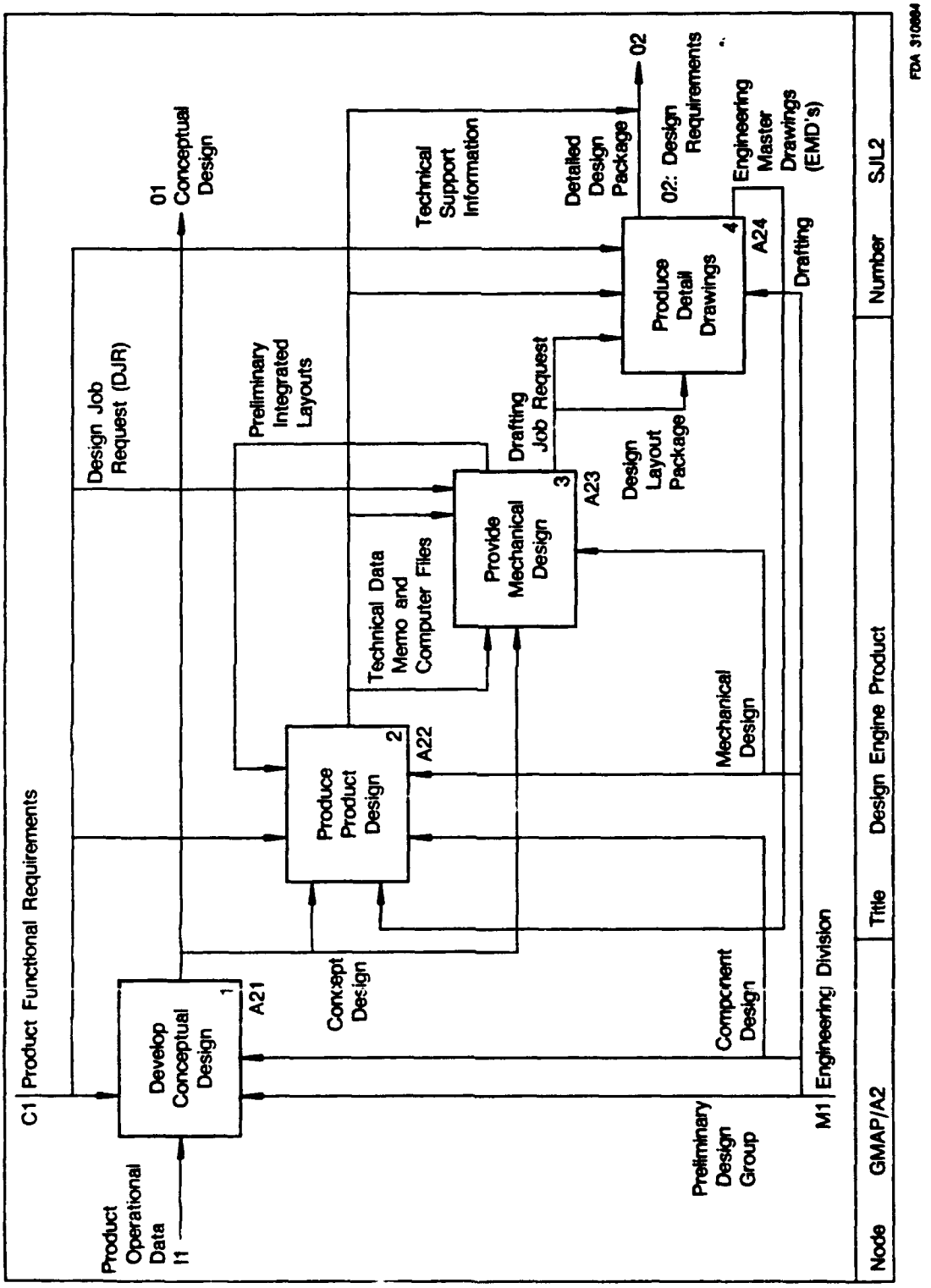


Figure A-4. Design Engine Product

The Aerodynamic and Durability groups, within Component Technology, generate the external and internal contours that are used to define the turbine airfoils. This design is further optimized using the results of streamline analysis, which accounts for the interaction of end-wall effects. Technical Data (TD) is communicated to the Structures Group for evaluating vibratory characteristics and to Mechanical Design to begin the part layout.

Several iterations may result from these analyses. These iterations may involve component or rig testing. The Component Technology support groups will conduct the tests they consider necessary to validate the design.

When the final design satisfies these groups, it is passed to the Mechanical Designer and other involved project groups through a Florida Technical Data Memorandum (FTDM). The TD is filed in the Design Job Record (DJR) of the Mechanical Designer. The Produce Final Product Design process is simplified for turbine disks, involving only the Mechanical Design and Structures groups, since the design of an externally cooled symmetric body of revolution is less complex. The Mechanical Design Group identifies candidate turbine disk shapes that meet the functional and structural life requirements while the Structures group addresses fracture mechanics considerations. After the disk design has been jointly optimized by Mechanical Design and Structure groups, Mechanical Design begins the part layout and Structures group issues an FTDM.

The third function, Produce Mechanical Design, includes all those activities that result in an approved design layout, which will satisfy the functional requirements established by management. These activities are the prime responsibility of the Mechanical Designer assigned to the project. It is within these activities that the final product design is analyzed and ultimately described in a form that will allow for its approval and release to drafting. The design package that is transferred includes the layout drawings and a DSM. Information relating to quality and to manufacturing, as well as Engineering Source Approval (ESA) requirements, is added.

The fourth function, Provide Detail Drawings, is the activity that results in the creation of formal detail drawings. The design layout package is combined with other design information and historical background data. This information provides the foundation for the GMAP/A3 function (Manufacture Engine Product). The design package is converted to manufacturing instructions that will enable production to make and inspect the engine product. The detail design package is the responsibility of the Drafting group, who first converts the design layout into Engineering Master Drawings (EMD) for blades only.

EMDs provide various two-dimensional cross-section and profile views of a particular part. These are reviewed by the Aerodynamics, Durability, and Mechanical Design groups to verify, through the use of overlays, that the design is the same as the original design approved by these groups. These EMDs are released to Manufacturing as soon as possible to minimize the procurement cycle for investment casting tooling.

Detail blade casting drawings are prepared and complete cooling hole locations are precisely defined for manufacturing. This design package is reviewed and approved for release. The package consisting of the layout, drawings, EMDs (airfoils only) and associated computer files as well as the component parts lists, is sent to Engine Product Configuration Support (EPCS). This group is responsible for the maintenance, reproduction, and distribution of the detail drawings.

The A3 Manufacture Engine Product, as shown in Figure A-5, includes the activities necessary to plan, provision, and produce turbine engine components. Incorporated are the major activities of:

- planning for manufacture;
- establishing budgets and schedules;
- creating production plans;
- providing production resources;
- procuring materials;
- producing the engine-related product.

Generally, each of the activities produces an output that becomes a control over other activities. External controls over the manufacturing function are the product design, the production capability possessed by the manufacturing facility, and the direction provided by management. The activities within this GMAP/A3 function generally correspond to those within the Composite View MFG/A0 function (Manufacture Product).

The first function, Plan for Manufacture, is concerned with developing and maintaining the plan that will support the manufacture of the product. Generally considered are the activities of:

- reviewing new product opportunities;
- developing production start-up plans;
- integrating all plans within manufacturing;
- monitoring performance;
- informing management of program status.

This activity responds to production requirements, product design requirements, and the master schedule, as a feedback from the budgetary and scheduling function.

The second function, Make and Administer Schedules and Budgets, produces schedules and budgets that provide adequate coordination among the various functions. This activity involves preparing a preliminary schedule and cost estimate based on initial manufacturing plans and then refining the schedule and budget as production details and bill of materials are developed. The ultimately produced master schedule relates to the final production plans. Over time, this function collects actual schedule and budget data, matches these to plans, and adjusts priorities as necessary. All accomplishments, expenditures, exceptions, and warnings are supplied to management in the form of reports. The major controls for these activities are the production requirements, the manufacturing plan, and the bill of materials.

The third function, Plan Production, relates to the tactical strategy necessary to produce engine products, providing manufacturing instructions, establishing inspection methods, and producing machine tool and gage definitions. The major activities encompass:

- the planning and scheduling of the production methods definition activity,
- the providing of manufacturing instructions;
- the establishing and documenting of the inspection instructions;
- the developing and specifying of accompanying tool designs.

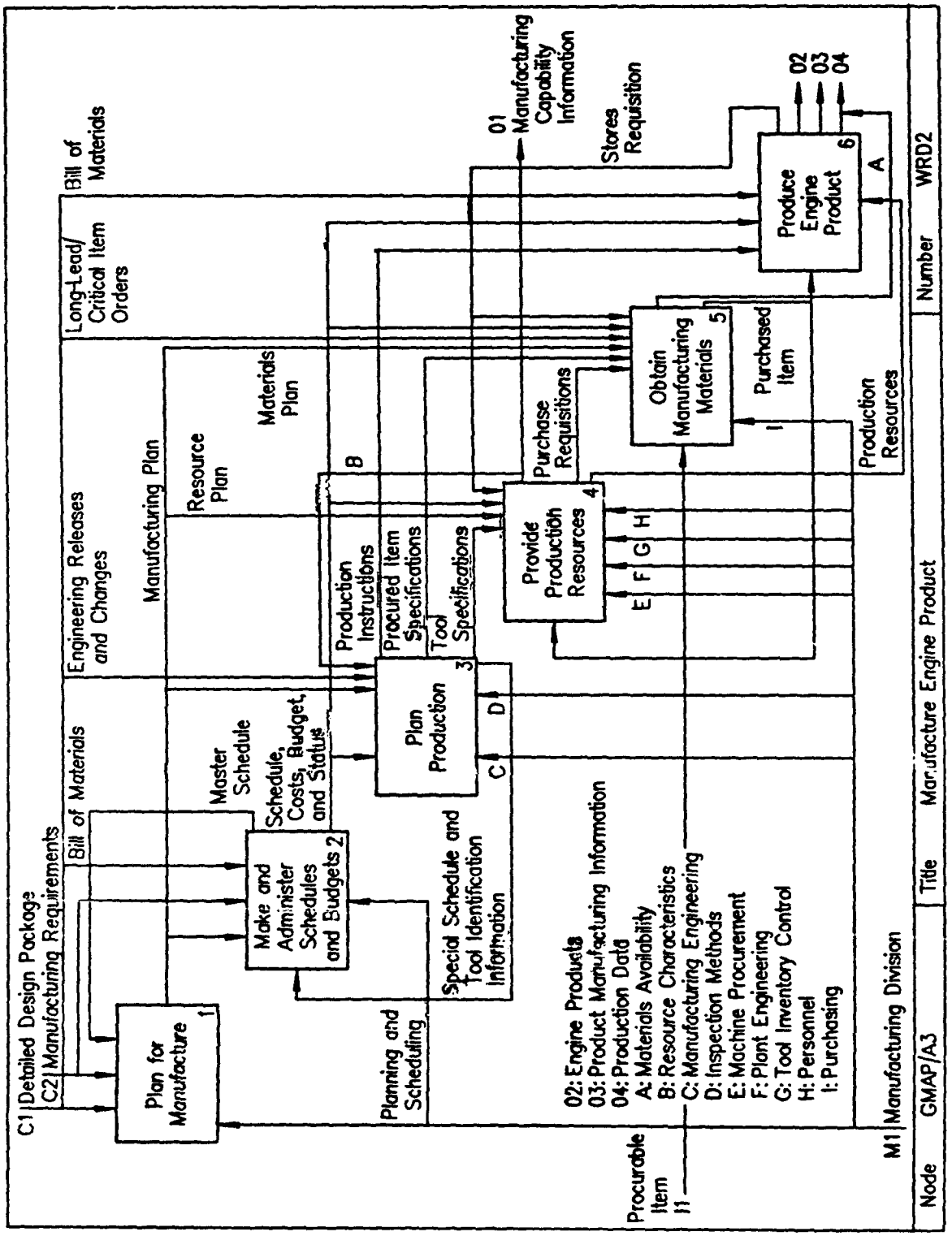


Figure A-5. A3 — Manufacture Engine Product

Also provided are numerical control tapes, computerized coordinate measuring instructions, machining instructions, and inspection instructions.

Items that provide control over this function include: the detailed design package from the GMAP/A2 function (Design Engine Products); requirements, related to capacity and capability within the production facility; and the quality assurance data that are supplied by quality engineering. This function at Pratt & Whitney differs from the Composite View MFG/A3 function (Plan Production) only to the extent that the numerical control and the coordinate measuring machine tapes are produced here instead of in the MFG/A4 function (Provide Production Resources).

The fourth function, Provide Production Resources, includes the activities of planning, provisioning, and acquiring the resources for the GMAP/A36 function (Produce Engine Product). This function provides four major resource outputs:

- facilities to house the production process and support services;
- equipment to transform the purchased material into the engine products;
- tools such as cutting tools, jigs, fixtures, and gages to be used in association with the equipment;
- trained people to perform the production tasks.

The interactions between this function and the other functions of this GMAP/A3 level of Manufacture Engine Product is relatively limited, although the primary controls collectively affect all of the functions. These controls include the manufacturing plan, the schedules, and the equipment/tool specifications, all of which are outputs from other functions within GMAP/A3 function (Manufacture Engine Product).

The fifth function, Obtain Manufacturing Materials, includes all phases of material acquisition from purchasing through in-house storage and distribution. Within this function, the problem of meeting the material needs called for in the manufacturing schedules is resolved by considering the level of the material inventory in hand and the material on order. Any deficiency leads to procurement of additional materials from suppliers. Also within this function is the inspection of the items delivered from suppliers. In-house material inventory management identifies material availability, distributes material when requested, and provides the record-keeping function.

Outputs from this function include procured raw material, vendor-produced components, and material inventory records date. This function reacts to the overall controls of the materials plan, schedule, and budget as well as an identification of critical and long/lead-time items. Inventory and inspection reports supply feedback to the procurement control activity.

The final function, Produce Engine Product, encompasses those activities in which the provided manufacturing materials are transformed into the engine products, using resources and plans provided by the foregoing functions. Engine products include not only complete engines but also items to meet spare part orders or inventory requirements. Within this production function, production control handles the scheduling and assignment of work on an orderly basis.

Inspection and test of the engine product to checkout conformance to specifications before the final packaging and delivering of the product to the user are performed. Controls on production include the parts list (bill of material), the schedule, [the master schedule, and the schedule from production control in Composite View MFG/A61 function (Control Production Orders)], and the manufacturing and inspection instructions.

Product data in the form of graphic and text descriptions impact each of the six functions within the GMAP/A3 function (Produce Engine Product) to varying degrees. However, it is only within the GMAP/A33 function (Plan Production) that the GMAP involvement appears to be significant.

The A4 — Provide for Product Support function, as shown in Figure A-6, encompasses the major activities that Pratt & Whitney undertakes to provide support for its engine products. There are four major activities:

- providing technical support relative to the engine products;
- processing the user requests for spare and replacement parts;
- supplying the user with requested ground support equipment;
- providing other support activities.

The four activities are generally performed independently of each other. Governing the performance of the activities are the support needs as expressed by the user, and the support requirements as expressed by the managers of the engine product.

Neither the Composite View MFG0 nor the DES0 model provides a decomposition of this function. Consequently, the function decomposition provided in the GMAP/0 model reflects the functional activities at Pratt & Whitney.

The first function, Provide Technical Support, uses product manufacturing information and transforms that function into product technical instructions. This activity is done in compliance with the support requirements. One of the most prominent of the product technical instructions is the Technical Order (T.O). Technical Order support is provided at three different levels:

1) at the flight-line level where the engine is in the plane and is covered by the airframe T.O.;

2) at the intermediate level where the engine is in the engine shop for maintenance and limited repair;

3) at the depot level where the engine modules are replaced and repairs are made with limited disassembly of the modules.

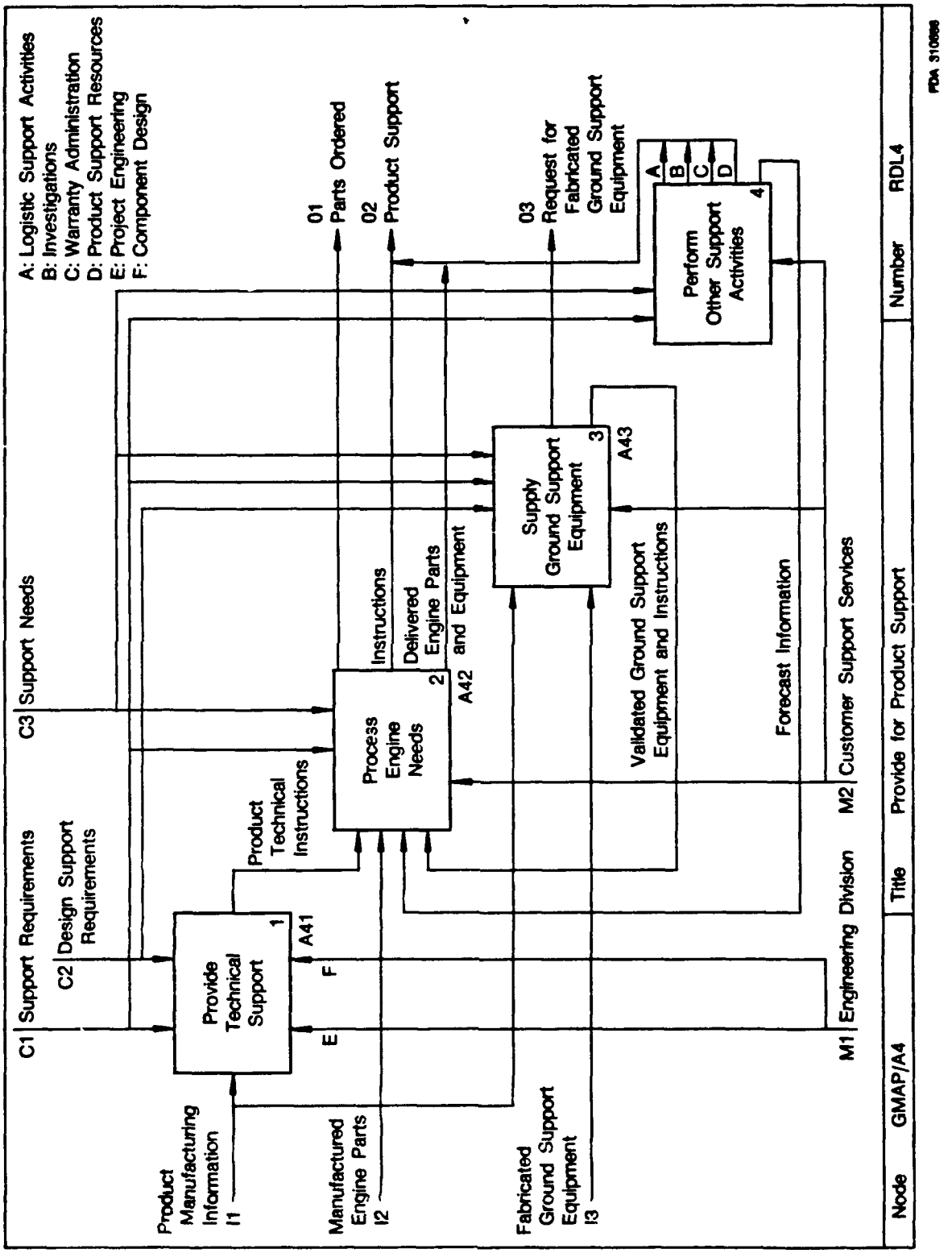


Figure A-6. A4 — Provide for Product Support

Technical Order support is also organized along four engine lines:

- OME (other mature engines such as the TF30, J52, JT8D, etc.);
- F100;
- RL10;
- Other (other, newer engines in development).

The second function, Process Engine Needs, is concerned primarily with ensuring that the engine needs of the user are satisfied according to the support requirements. This function includes the processing of replacement and spare engine part orders. All engine part orders go to East Hartford where part production is scheduled. The manufactured engine parts, as well as the fabricated ground support equipment that has been validated, is processed through this function and is provided to the user.

The third function, Provide General Support Equipment, is responsible for developing and supporting special tooling. The tools supplied are considered to be over and above the cost of the engine. A requirement for ground-support equipment must be acquired. If the requirement is for special support equipment, it is designed within the function with the resulting design being released for fabrication. Once fabricated, the support equipment is validated and support equipment instructions are generated. The equipment and instructions are then made available to the user through the second function of processing user engine needs.

The fourth function, Perform Other Support Activities, encompasses many activities; however, these activities, although important, would not be influenced by the GMAP. They include:

- developing logistics support analyses for new engines;
- investigating mishaps and incidents related to an engine in the field;
- developing and administering a warranty program;
- providing product support resources;
- developing forecasts.

Because this function will not be decomposed in the next level, these activities will be discussed in greater detail in this level.

The USAF requires a logistic support analysis for all new engines and for major engineering changes. This analysis evaluates product life cycle costs and is completed early during the engine design phase.

Because there is no military equivalent to the civilian NTSB (National Transportation Safety Board), Pratt & Whitney is sometimes requested by the USAF to participate in the investigation of incidents (which involve no loss of life or property) or mishaps (which involve the loss of life or property) related to the engine. Pratt & Whitney will review the incident or mishap in the field. If needed engines and other appropriate pieces will be brought back to Pratt & Whitney for investigation. Engine maintenance records are also checked as part of the review.

The warranty program is negotiated with the user. Once established, the program requires administration. Investigations are performed to determine the validity of a user claim against the warranty. A key element of the investigation is determining whether the deficient part is a Pratt & Whitney part.

Pratt & Whitney provides for engine overhaul at their Southington, CT, facility. In addition, Pratt & Whitney has field representatives at the USAF overhaul facilities such as the one in the San Antonio Air Logistics Center at Kelly Air Force Base, TX.

Spare-parts forecasting is an important activity within this function. A five year horizon has been adopted for these forecasts.

APPENDIX B

COORDINATION WITH OTHER CIM PROJECTS

1.0 PRODUCT DEFINITION DATA INTERFACE PROGRAM

McDonnel Douglas was included on the GMAP team to provide expertise with the Product Definition Data Interface (PDDI) program. The McDonnell Douglas personnel under contract to Pratt & Whitney for GMAP were the same people responsible for the PDDI program. This enabled Pratt & Whitney to maintain close ties with PDDI. Based on the GMAP needs and requirements, this helped Pratt & Whitney decide on, and implement, appropriate enhancements to the PDDI system components to complete the GMAP design.

Early in the program, McDonnell Douglas conducted a special technical workshop to give Pratt & Whitney a working knowledge of the components of the PDDI system. McDonnell Douglas also assisted in getting the PDDI software loaded and on-line on Pratt & Whitney's computer network.

Later in the program, McDonnell Douglas's technical efforts became fully integrated into the program as they undertook their assigned responsibilities.

2.0 INTEGRATED INFORMATION SUPPORT SYSTEM

The Integrated Information Support System (IISS) program was investigated through attendance at meetings and presentations. It was suspected that GMAP should be aligned with the work being done on the Common Data Model (CDM).

At a high level overview of the IISS program, held in September 1987, it was determined that the focus of GMAP and the focus of IISS were quite dissimilar. GMAP focused on Product Definition Data (PDD) that captured the design intent of a single product, and are used throughout the product life cycle. GMAP concentrated on the exchange of PDD and provided mechanisms to accomplish this. IISS concentrated on the communication from one database format to another. Typical applications using IISS did not use PDD The IISS focus was primarily on business oriented product data, such as scheduling and inventory control. In addition, IISS did not support graphics required in GMAP.

3.0 INTELLIGENT TASK AUTOMATION

It was difficult to identify a point of contract with the Intelligent Task Automation (ITA) program. Investigation dealt primarily with obtaining documentation on the work done on the ITA programs. This documentation helped GMAP understand the needs of future applications that could benefit from rich PDD.

4.0 FACTORY OF THE FUTURE

The Factory of the Future (FOF) project ceased to exist early in the GMAP project. Had it continued, it might have been a framework for GMAP development of PDD integration. It might also have helped in the area of finance and other administrative areas.

5.0 STANDARDS ORGANIZATIONS

GMAP was involved extensively with the various standards organizations. Several meetings and discussions were held with Mr. B. Smith of the National Bureau of Standards, later National Institute of Standards and Technology (NIST), to discuss the possible roles of the GMAP effort within the standards community. One area of coordination dealt with PDES. Pratt & Whitney intended to help extend the industry standard for PDD by pushing the technology in this area. The intent was to use the existing PDDI as a base for extending PDD.

Another area of interaction in the standards community dealt with IGES. GMAP personnel supported the effort to improve IGES and worked with the American Society of Mechanical Engineers to update the existing ANSI Y14.26M Standard on Digital Representation for Communication of PDD.

All GMAP team companies actively participated with the NIST IGES/PDES efforts. This participation spanned the full spectrum, from membership on the IGES steering committee, to committee chairpeople and members of working committees. As work progressed on GMAP, the team ensured that information was disseminated to the appropriate committees within IGES/PDES. This was accomplished by making technical reports (based on Air Force approval) available, by presenting technical information to the committees, and by personal interaction with the IGES/PDES committees. The intent was to share technical information with these groups and provide needed assistance.

5.1 IGES/PDES

- In July 1986, two members of the Pratt & Whitney GMAP technical team participated in an IGES/PDES conference held in Seattle, Washington. They had an opportunity to both review and discuss issues surrounding PDD with committee members and to report GMAP technical progress. In addition, the Air Force's GMAP Program Manager gave a presentation on the Air Force's expectations of PDES. The exchange of technical information was beneficial to the GMAP effort.

- A PDES/MPC (Mechanical Products Committee) meeting was held at Pratt & Whitney in late 1986 to review the PDES/MPC IDEF1X information model that the committee was developing. Pratt & Whitney was the last in a series of companies visited prior to the PDES/MPC submission of its recommended information model to the main PDES committee. The main purpose of the visit was for validation of the model in its current state. The PDES/MPC meeting concerned the approach, technique, interpretation, and alternatives to the respective model concepts. Several PDES/MPC model entities addressed: approval and effectivity, physical interface, products made from other products, and mechanical products in general. The PDES tolerance or form features models were not yet incorporated. The concensus was that the project currently was incomplete, and needed to be extended to complete its intent. However, this topic was outside the realm of the meeting.

- Program representatives from Pratt & Whitney, United Technologies Research Center (UTRC), and MCAIR attended the October 1986 IGES

committee meeting in Huntsville, Alabama to exchange information with the IGES committee concerning issues on the PDES development activities. A question was raised concerning how the PDES personnel would receive the GMAP schema information. It was concluded that the PDES group would have to request this information from the Air Force. As part of the PDES/MPC's report, it was decided that the Peoria project would continue, starting 10 November 1986. Mr. M. Dunn of UTRC agreed to organize a special interest session in Peoria, Illinois dealing with features.

- In November 1986, a workshop concerned with initiating PDES modeling of form features was organized and chaired by Mr. M. Dunn UTRC. The session, conducted as part of the MPC effort, was attended by representatives from 12 companies, including the prime GMAP subcontractors, McDonnell Douglas and ITI. As a result of the conference, planning for a concentrated PDES effort on form features was initiated.

  In addition, Mr. M. Dunn and Mr. K. Perlotto from Pratt & Whitney performed substantial work on PDES shape tolerance modeling. They reviewed a working model, and suggested refinements. The model was "normalized" by Mr. Perlotto, and a candidate "integration" of that model with the mechanical products model, was developed by Mr. Dunn.

- The January 1987 quarterly meeting of the IGES organization included a two day session of the Edit committee, where each discipline committee presented their application models developed for PDES. These sessions were attended by Mr. M. Dunn and Mr. K. Perlotto. The plan was to perform a model integration on these application models to create an "initial testing draft."

  Subsequent meetings of the Logical Layer Committee evaluated the discipline committees' evaluations of readiness for the integration process. Based on this, it was determined that the integration for the initial testing draft would be termed the "resource models". Resource models form the supporting foundation for other models. They were the curves and surfaces model, the constructive solid geometry (CSG) and boundary representation (BREP) solids models, and the shape tolerance model.

  The actual integration was performed the week of 26 January in St. Louis, Missouri. K. Perlotto attended and contributed to this integration process. The integration also extrapolated a hierarchy, or taxonomy, for PDES, as the models depicted it. This structure was similar to the GMAP schema and the PDDI schema, with the PDES scope.

  The Logical Layer Committee and others noticed that the discipline organization of committees was not optimal. K. Perlotto and others suggested that an organization along data class lines would be more appropriate. This suggestion was drafted in the form of a recommendation from the Logical Layer Committee chairman to the PDES leadership.

- A representative from the GMAP technical team attended the 30 March to 3 April 1987 joint meeting of subcommittee ISO/TC184/SC4/WG1 STEP and

the PDES organization at the Airport Hilton in West Palm Beach, Florida. This meeting was a technical coordination meeting between the ISO development of the STEP and the United States' effort on PDES.

The ISO subcommittee was documenting and distributing integration methodology plans to modelers in the STEP effort. A planning model was applied for this purpose. Application modelers did not model interests outside their discipline, but interfaced with the appropriate group(s) to obtain the needed support (the modified data class approach). This strategy was used effectively in the GMAP schema development process, and was recommended to the PDES Logical Layer Committee by GMAP participants.

File Structure Committee SG3 and the ad hoc EXPRESS committee met jointly for several days to discuss the problems with EXPRESS and the mapping of EXPRESS to the file structure. Experience with the EXPRESS language in the development of the PDES Initial Testing Draft and in the GMAP schema specification tested the language with large, complex examples. These exercises uncovered minor problems and tested the capabilities of the language for its intended purpose. These experiences precipitated the joint meeting of these two committees to discuss these issues.

- Personnel from ITI, UTRC, and McDonnell Douglas participated in the initial working session of the PDES subcommittee on form features in April 1987. The session was hosted by ITI. It produced a substantial "starter" IDEF1X model for form features information. Among the resources of the subcommittee were working documents from GMAP. These were approved for public release by the Air Force to permit PDES access.

- A GMAP representative attended the quarterly meeting of the IGES/PDES organization held 20-24 July 1987, in Monterey, California.

  Highlights of the meeting included a presentation by Mr. T. Moffett from Northrop on the creation of an industry cooperative to accelerate the development of the PDES Version 1.0 specification. The Logical Layer Committee, responsible for the integration of reference information models into a single PDES specification, laid the groundwork for the development of a resource model for Product Structure and Configuration Management.

  In addition, a subcommittee of the MPC was formed to create a model of form features. This work was initiated by Mr. M. Dunn from UTRC. The GMAP Form Features submodel was set forth as a starting point. Mr. R. Gale, from D. Appleton Company (DACOM), presented the status and overview of the form features model in Mr. M. Dunn's absence at the IGES/PDES Monterey meeting.

- Mr. K. Perlotto from Pratt & Whitney participated in a 1 week working session for the PDES Form Features Committee hosted by Mr. M. Dunn of UTRC, at UTRC in East Hartford, Connecticut, 14-18 September 1987. The committee's work involved the review of the information modeling effort in

form features to date, and the continuation of that work. The 13 committee participants represented 11 different companies, both in and out of the aerospace industry. The meeting concentrated on the refinement and attribution of the existing information model. The meeting also expanded on areas that were thought to be incomplete in the model.

The meeting resulted in a better understanding of the scope and content for the model and the relationship of the model to the PDES shape area, and the stabilization of the model structure and content. GMAP representatives continued to contribute to the modeling and its documentation.

- Mr. K. Perlotto from Pratt & Whitney attended the IGES/PDES/ISO joint quarterly meeting held at the Chase Park Plaza Hotel in St. Louis, Missouri, 12-16 October 1987. Mr. Perlotto concentrated his efforts in a committee meeting concerning the Logical Layer, which was actually meeting as the ISO Ad Hoc Committee on EXPRESS. Issues concerning the content, use, and intent of the EXPRESS language for information modeling were debated. The experiences and attitudes gained on several issues through the GMAP utilization of the EXPRESS language in the GMAP Conceptual Schema specification were conveyed to the committee.

- Mr. K. Perlotto participated in two PDES integration workshops held at NIST 27-29 October and 30 November-4 December 1987. These meetings were organized and run by DACOM under the PDES assistance clause from the PDDI Extension contract. The primary purpose of the meetings was to develop an integrated PDES IDEF1X model of several available topic and resource information models.

  The work in the first meeting was partially integrating IDEF1X models called Shape/Size Element Group (SSEG), and Product Structure/Configuration Management (PSCM) models. It was decided to manage these models under JANUS.

  Attendance was essentially the same at the second meeting, with some notable European additions from the International Standards Organization (ISO). The 43 issues raised at the previous meeting were addressed.

- Mr. K. Perlotto attended the IGES/PDES quarterly meeting 11-15 January 1988 in San Francisco, California. The Manufacturing Technology Committee conducted a detailed review of the PDES Tolerances model. Mr. M. Dunn from UTRC introduced several refinements that were incorporated into the model.

  The MPC devoted one day to the review and comment of the PDES Form Features model developed by M. Dunn. Primary modelers M. Dunn, and Mr. S. Gallo, also from UTRC, presented an overview of the GMAP portions of the model and K. Perlotto discussed the IDEF1X to EXPRESS conversion process.

The PDES Technical Planning Committee determined that the integration group would be accepted as the Integration Subcommittee of the Logical Layer Committee. The Integration Subcommittee decided to hold a integration working meeting 19-22 February with the chairpersons of the committees in attendance. Mr. K. Perlotto was the EXPRESS resource and Ms. Y. Yang from DACOM was the facilitator.

In ad hoc EXPRESS Committee activity, K. Perlotto met with Mr. P. Kennicott from General Electric, representing the testing draft, and both Mr. N. Shaw and Mr. J. Owen from the University of Leeds to discuss Mr. Shaw's and Mr. Owen's review and comment of the latest EXPRESS specification, N177. In the process of implementing a parser for syntax checking EXPRESS, Mr. Shaw and Mr. Owen uncovered many inconsistencies with the document. A consensus was reached to resolve the inconsistencies and the details were forwarded to Mr. D. Schenck from McDonnell Douglas for review and inclusion in the final N177.

- Three GMAP team members, Mr. K. Perlotto, Pratt & Whitney; Mr. M. Dunn, UTRC; and Mr. W. Burkett, McDonnell Douglas; attended a 5 day PDES integration workshop held at the Quality Inn in Gaithersburg, Maryland on 18-23 February 1988. It was felt by those in attendance that this workshop was, by far, the most successful technical interaction session to date. The team worked to develop a strategy for the integration of the various models [tolerance, solids, form features, finite element, Product Structure & Configuration Management (PS/CM), geometric modeler, and GMAP]. The primary area addressed involved the way that the application models were to access the resource model for shape, and how those models interfaced to the PS/CM data.

  The main accomplishment of the meeting was the acceptance of the GMAP schema's approach to the generalization of shape into "real things". This approach was successfully used for GMAP schema development during the integration process that allowed the separate data class models to reference geometry. The individual topical models refer to categories of shape elements such as object, volume, area, seam, and location, which are real things. These real things can have many representations, in any of the shape models.

  The acceptance of this GMAP concept and approach, and its adaption to the PDES environment, represented a milestone in technology transfer. A concept developed under a government project as a solution to a problem was accepted as an attractive solution for helping the development of a national standard. The PDES integrators, after agreeing to follow this strategy, discovered that it allowed the integration of shape with tolerances, form features, and finite element modeling models without much difficulty. The "real thing" acceptance represented the fruition of the PDES Shape-Size Element Group (SSEG) concept.

- Mr. Perlotto and Mr. Dunn also attended the IGES/PDES/ISO Joint Quarterly Meeting held the week of 27 March 1988 in Washington, D.C.

Mr. Dunn presented a walkthrough of the integration core model developed at the PDES February workshop that was based on using the GMAP approach to the generalization of shape into "real things".

The GMAP approach solved approximately 80 percent of the issues raised at the initial integration workshop. In general, all the committee chairs, and model owners were pleased with the direction that the integration took, and supported the full implementation of the concepts in PDES.

Because both IDEF1X and EXPRESS models were being used in PDES work, it was necessary to determine if the IDEF1X and EXPRESS of a model were equivalent. It was decided to assemble an ad-hoc group (under edit committee request) to investigate the need for correlation of the various forms that the conceptual models would take in the specification. This ad-hoc group was led by Mr. Perlotto.

- GMAP personnel attended the fourth PDES Integration Workshop the week of 13-17 June 1988, held at DACOM in Manhattan Beach, California. It was determined that the Integration Committee would produce the portion of the PDES specification known as Volume 3. This document would contain the integrated IDEF1X model for PDES.

  The Integration Core Model, which represents the shape representation interface via idealized or "real" shape concepts, was refined to address the outstanding issues against it, and to allow further capabilities. The changes in the model did not affect the original structure or concepts that the model contained. Mr. K. Perlotto would prepare the latest EXPRESS rendition of the model and forward it to the committee for inclusion in the Volume 3 specification.

- GMAP personnel attended the IGES/PDES/ISO joint quarterly meeting held in Denver, Colorado at the Hyatt-Regency Hotel 11-15 July, 1988. Mr. K. Perlotto would be preparing another version of the form features model by Mr. M. Dunn, from the United Technologies Research Center (UTRC); and an updated version of the Integration Core Model would be available before that date. Mr. Perlotto would also conduct an in-depth review of all aspects of the ITD - Denver version.

  Integration Committee meetings involved an in-depth review and refinement of the current model due to issues, concerns, and proposals introduced by M. Dunn. The status of all the other models for inclusion were reviewed. A formal documentation standard for the PDES Volume 3 document (IDEF1X models) was reviewed and adopted. The next workshop was rescheduled from the week of 22 August to the week of 8 August, in St. Louis, Missouri, in response to the schedule deadline of 8-14 August for the next ITD.

- The fifth integration workshop of the PDES integration Committee was attended by GMAP personnel. The workshop was held 19-23 September, 1988, and was hosted by McDonnell Douglas Astronautics Company in Huntington Beach, California.

  The integration workshop addressed all issues proposed against the integration core model. In over 3 days of discussion, only one issue resulted in the deletion of two entities. Two new entities were created. This attests to the acceptance and stability of the integration core model. The group also addressed the "complete issues" log of the committee, and disposed of dozens of issues contained there, leaving a few open for future reminders.

- The IGES/PDES/ISO joint quarterly meeting, held 17-21 October 1988, in West Palm Beach, Florida, was attended by GMAP personnel. The state of the PDES/Standard for the Exchange of Product Model Data (STEP) specification of the West Palm Beach version of the PDES Testing Draft, and accompanying documents, would be submitted to the parent body in ISO at the 28 November-2 December meeting in Tokyo, Japan. The parent body of ISO TC184/SC4/WG1 would receive the STEP specification, physical file format, EXPRESS language, mapping from EXPRESS to physical file, and the integrated reference model documents.

- GMAP personnel reviewed Standard for the Exchange of Product Model Data (STEP) documents N301 and N302, a proposal for STEP geometry, and a proposal for STEP Geometry, Topology, and Shape Representation. These proposals have modifications since the Denver '88 PDES draft proposal. GMAP personnel determined a strategy for PDES implementation, given that the specification is in the process of continual modification and refinement. GMAP personnel felt that it would be more productive to expand the PDES subset to include more complicated defined types and entities. This would further test the system components' ability to handle PDES when the Integrated Product Information Model (IPIM) is finalized.

- An IGES/PDES quarterly meeting was held 15-20 January 1989 in San Diego, California The submittal of STEP to the ISO in December 1988 was accepted by the ISO for registration as a draft proposal. The ISO secretariat circulated a letter ballot to include voting by each member country on each clause and each section of the draft proposal.

  In another area, it was publicly declared by Mr. Brad Smith that IGES development will continue beyond the release of IGES V5.0. There had been statements in the past that the IGES project would terminate with the V5.0.

- In accordance with the statements of work for the GMAP contract, the Air Force approved the technology transfer of GMAP software and architecture to the PDES National Test Bed Project at NIST. The task will involve the establishment of a Pratt and Whitney employee as a NIST research associate at NIST. The work will include the installation of the GMAP software at NIST to provide an environment in which PDES testing may occur. In

addition, there will be some migration tasks to move a GMAP demonstration application to execute in the PDES environment, therefore providing proof-of-concept that the product data technology developed under GMAP is applicable to PDES. The duration of this support to NIST is to be 6 man-months.

5.2 ANSI Y14.26M SUBCOMMITTEE

The IGES/PDES groups are working on the development of specifications. The work being done by these groups is passed to the appropriate organization sanctioned to produce national standards. The prime organization related to GMAP was the American National Standards Institute Y14 subcommittee 26M. This subcommittee was chartered to coordinate with interested groups to review and obtain approval for a standard for information structures to be used for the digital representation and communication of PDD. The ANSI Y14.26M standard reflected the technology level of IGES version 1.0, which was established as a standard in 1981.

This ANSI subcommittee, inactive for a period of years, was reactivated during the PDDI program to upgrade the existing standard to reflect the developments within the IGES/PDES committees. The first major undertaking by the reactivated committee was that they would pursue upgrading the existing standard to reflect the IGES version 3.0. This was expected to take at least 13 months, implying that a new standard should be established sometime after August, 1987. The next step for this committee was to work with the NIST PDES groups, and Government programs such as GMAP, to begin the process of taking this specification forward for standardization. ANSI/GMAP Coordination activities are described below.

- In June 1986, ANSI subcommittee Y14.26M met to review IGES version 3.0 and to submit the new specification to ANSI to begin the public balloting process to obtain acceptance of this specification as a standard. Two members of the GMAP team attended this meeting; Mr. B. Birchfield from McDonnell Douglas, who was the chairman of the Y14.26M subcommittee, and Ms. L. Phillips from Pratt & Whitney, who was a member of the subcommittee.

- Pratt & Whitney's GMAP Program Integrator, Ms. L. Phillips, attended the ANSI Y14.26 meeting in Sarasota, Florida, on 1-2 October 1987. This was a joint meeting with the ANSI Y14 main committee. During this meeting, it was reported that the ANSI Board of Standards approved the ANSI/American Society of Mechanical Engineers (ASME) Y14.26M-1987 standard based on IGES Version 3.0 on 2 September 1987.

  Another major item discussed at this meeting was the investigation of alternate approaches to help resolve the length of time it takes for standardization. An action item from the June 1987 meeting was a survey of ANSI Y14.26 subcommittee members on issues surrounding the standardization activities and the issue of reorganization of the Y14/Y14.26 committees. The findings of this survey were presented at this joint meeting. It was recommended that ANSI Y14 undertake a study to review the scope of Y14 committees activities to provide:

  - recognition of continuing need for existing standards,
  - recognition of new concepts and new technologies,
  - coordination of complementary standards development.

As a result, an ad-hoc committee was formed to address these issues consisting of members from both the Y14 main committee and the Y14.26 subcommittee. Pratt & Whitney's GMAP Program Integrator, Ms. L. Phillips chaired this ad-hoc committee.

- Ms. L. Phillips, and McDonnell Douglas's Program Manager, Mr. H. Ryan, attended the ANSI/American Society of Mechanical Engineers (ASME) Y14.26 meeting held in Albuquerque, New Mexico, on 18-19 January 1988. Ms. Phillips gave a presentation on the current status of the GMAP contract and Mr. Ryan showed the PDDI Extension end of contract videotapes to the group. The main focus of the meeting was to revise the scope of Y14, the possible reorganization of Y14, and/or Y14.26, and the coordination of efforts in the electrical/electronics standards area.

  The ad-hoc committee on reorganization issues gave a presentation on its study. The group continued to work on the creation of a new scope for the Y14 main committee that would encompass the development and maintenance of national standards for product data and related control systems needed to support the life cycle of the product. The scope would support standards regardless of the source medium (i.e., paper, film, and digital). The source medium issue appeared to be the root of most problems in the Y14 because only Y14.26 appeared to address the digital issues. Strategies included discussions with the IGES/PDES communities to form stronger ties between the creators of the specifications and the standardization organizations.

  Another topic of interest was the planning meeting for a series of workshops on mechanical tolerancing being proposed by ASME to the National Science Foundation for funding. These workshops addressed the identification of basic and generic issues dealing with computer representation of mechanical tolerancing to permit unambiguous communication between design, manufacturing, quality control and inspection, and total field application. The overall goal of the project was to describe the state-of-knowledge of mechanical tolerancing and to suggest priority areas of research required by industry and government. To ensure that the planners of this workshop were aware of the PDDI and GMAP work in this area, as well as the IGES/PDES work, L. Phillips and H. Ryan offered to provide a representative of the PDDI and/or GMAP contracts to this planning session. Mr. M. Dunn from UTRC was selected to attend. The first planning session took place on 27-28 January 1988.

- Ms. Linda Phillips and Mr. Jack Irvine attended the ANSI Committee/American Society of Manufacturing Engineers (ASME) Y14.26 meeting held in Milpitas, California, on 13-15 April 1988. Ms. Phillips was approved as the new Chairman of the committee. She is serving from April 1988 through May 1991. It was hoped that during this time a version of PDES will be submitted to the committee for standardization.

  The April meeting focused primarily on obtaining the status of the documentation of the new ANSI/ASME Y14.26 1987 standard (IGES Version

3.0). Publication of the standard has been held up due to editorial corrections and artwork. The group also discussed the need to test PDES. It was determined that development of a test plan was imperative. Ms. Phillips contacted NIST, the CALS office, and the PDES Cooperative to determine what test plans these organizations had.

- Ms. Linda Phillips and Mr. Jack Irvine attended the ASME/ANSI Y14.26 meetings held 4-5 August and 3-4 October 1988. The August meeting focused primarily on reviewing MIL-D-28000, harmonization activities, and PDES testing. The focus of the October meeting was on IGES Version 4.0 standardization, a technical report on PDD and Interactive Computer Graphics Systems, and the findings of the ASME Tolerancing workshop.

- Ms. Linda Phillips attended the ANSC/ASME Y14.26 meeting held in San Diego, California, on 12 and 13 January 1989. The primary focus of the meeting was on reviewing the IGES Version 4.0 standardization activities and recent developments regarding PDES. Other items discussed were DMIS standardization and the mathematization of Y14.5.

  Developments regarding PDES are of prime interest to the GMAP community. At the ISO meeting in Tokyo on 28 November 1988, PDES was voted to the status of an ISO working draft. A 3 month comment period will begin in March. The 1200 page document may be ordered, for a fee, from the National Technical Information Services at (703) 487-4650. Although PDES is under comment in the ISO community, the PDES organization continues to mature the specification for submittal to ANSI for consideration as an American National Standard. The time-frame for this submittal has not yet been determined. It is not expected to occur until early 1990.

6.0 CAM-I

Pratt & Whitney held several meetings with Mr. P. Downey of CAM-I to review areas for coordination efforts. It was determined that it would be beneficial to coordinate efforts in the area of applications interface. GMAP work to define the minimum requirements for a geometric modeler was considered of interest since it would help CAM-I define the functional requirements for a modeler. This work also helped determine the role of the access software in GMAP. These meetings also led to the inclusion of a demonstration of an interface into DMIS in the GMAP end of contract demonstrations.

7.0 COMPUTER-AIDED ACQUISITION AND LOGISTICS SUPPORT

- Linda Phillips presented a GMAP overview at a NIST meeting on CALS initiatives 24-25 June 1986. The CALS program has the objective of integrating the design, manufacturing and logistics functions through the efficient application of computer technology. CALS has the additional goal of developing a unified interface with industry for the exchange of technical data in digital form.

The presentation focused on the need to electronically transfer complete product data and how this would benefit the logistic support community. It was noted that many of the same functions that occur in field support have been accomplished in the design and manufacture of a product. The ability to transfer and use applicable product data models would support the CALS goals of reducing paper, and also make efficient use of the electronic media to obtain, maintain, and produce these important data.

- GMAP's liaison for subcontractors, Mr. Jack Irvine, attended a NIST meeting in January 1987 that included a CALS workshop. The purpose of the workshop was to get recommendations from industry on selecting "core" requirements for standards that would support the development of digital representations and archiving graphics data.

  Rockwell and Grumman both described their experiences transferring engineering drawings to automated publications systems using digitizers, IGES conversions, and text/graphics mergers. IGES conversions were not cost-effective nor were they accurate. The Society of Automotive Engineers (SAE) was working on validation techniques for IGES software implementations with clear definition of the level of entity support.

  Raster transfer of data appeared to be more cost-effective when used by technical publications groups than vector data. Technical publications do not require the accurate geometry that is necessary for manufacturing, but can use compressed raster displays that can be edited for removing dimensions and inserting text.

  There was evidence of growing confidence in the services that delivery of technical orders, maintenance data, and logistics information can optimally be received from contractors in raster form using optical disk systems. Standard MIL-STD-1840 was issued by the Department of Defense (DoD) to describe the rules for the method of electronic delivery.

- The Pratt & Whitney GMAP Program Manager, Mr. Richard Lopatka, attended a CALS-initiated DoD Cooperative meeting for PDES, held 19 June 1986 in Washington, D.C. Many aerospace companies attended. A prospectus was put forward by an ad hoc group to establish an organization chartered to accelerate the development of PDES. Companies involved in this effort include Northrop, Boeing, Grumman, and McDonnell Douglas.

- Mr. Jack Irvine, GMAP's supplier liaison, attended a CALS workshop at NIST in Gaithersburg, Maryland in September 1987. Year end presentations were made on the progress CALS had made in defining the electronic transfer of technical documentation. CALS was expected to be a contractual line item in at least four major weapon systems contracts by 1990.

8.0 INTEGRATED DESIGN SUPPORT SYSTEM

In late 1986, members of Pratt & Whitney GMAP office met with the Pratt & Whitney member of the IDS Technical Advisory Group (TAG) to obtain a briefing of the IDS program.

The IDS program focused on the capture, management, and communication of technical data from design through logistics operations. The IDS program was also concerned with data models, but its primary work was in data management, networks, communications, standardization, and data security.

GMAP complemented the IDS program by defining the PDD schema needed to support the life-cycle applications; i.e., GMAP was helping to define the PDD that would be standardized by PDES efforts. The IDS program was defining the environment and architecture that would access, control, and manage this PDD information. The IDS program had developed a Product Control model. GMAP developed a PDD model. Within the GMAP PDD schema structure, the two programs overlap at the GMAP Administrative and Assembly level.

Mr. Richard Lopatka attended the TAG meeting for the IDS program held in Dayton, Ohio on 7 and 8 April 1987 and gave a presentation on the technical status of GMAP.

9.0 OTHER

- As part of the GMAP's efforts to transfer information to the industrial community, two program members participated in a Society of Manufacturing Engineering (SME) workshop on data exchange in March of 1986. Mr. Robert Lessard from UTRC and Pratt & Whitney's *GMAP Technical Coordinator*, Mr. Ralph Disa authored a paper, "Identification of Product Definition Data in a Manufacturing Enterprise — A Case Stud". The report detailed program methodology for obtaining a clear understanding and use of PDD as it pertains to the life cycle of complex structural components of jet engines. This paper also gave a briefing on GMAP's technical progress using the methodology.

- Mr. George Leistensnider from Pratt & Whitney presented the goals and objectives of the GMAP program to the Forging Industry Association on 12 June 1986. This presentation focused on the anticipated benefits of GMAP to the forging community. The presentation was well received and a number of companies expressed an interest in attending future Industry Review Boards as well as requesting to be on the distribution list for program documentation. Several suppliers expressed an interest in being added to the list of supplier demonstration candidates.

- Mr. Richard Lopatka, attended a National Security Industrial Association (NSIA) meeting held 13-16 July 1986 as an invited panelist and presented a GMAP overview. The objective of the meeting was to establish a foundation for government and industry cooperation specifically aimed at implementing CALS. The panel topic was "Computer Aided Design/Computer Aided Engineering (CAD/CAE) Design Integration for Improved Reliability and Maintainability".

- Ms. Diane Koziol Emmerson from Pratt & Whitney presented a paper, "Use of Product Models in a CIM Environment," to the CIMTECH '87 Conference in Los Angeles, California during the week of 23 March 1987. The conference was sponsored by the Computer & Automated Systems Association of the Society of Mechanical Engineers (SME). Approximately 100-150 people from industry and academe attended this segment of the conference, which focused on Supporting Technology.

  This paper discussed the methods used to design product data information models for use in a CIM environment. The information model content, structure, and capabilities to convey product shape and nonshape information normally communicated by the engineering drawing, were also discussed. In addition, the use of these models to integrate and enhance product life cycle activities was discussed.

- In mid 1987, Mr. Richard Lopatka attended a ManTech sponsored industry review of FIMS. This industry meeting, held to review a study contracted to Cincinnati Milacron, examined ways to better develop and use across factory floor applications software funded by the Air Force. The need for more use of standards in software interfaces was highlighted. Several other industry representatives associated with the GMAP Industry Review Board attended.

- Mr. Don Deptowicz from Pratt & Whitney attended the REPTECH '88 workshop in Salt Lake City, Utah, 25-27 January 1988. The primary purpose of this workshop was to disseminate information concerning new repair technologies and related CIM activities throughout the DoD maintenance facilities. During the CIM Technology exchange, Mr. Deptowicz presented a paper, "Implementation of GMAP Technologies for Logistics Support Applications". Although the primary focus of the workshop was on automation applications and the flexibility that they provide in a repair environment, particular emphasis was placed on the flow and exchange of PDD.

- Mr. Perlotto also attended and presented at the Product Data Initiative (PDI) form features Workshop held at the Martin Marietta Energy Systems in Oak Ridge, Tennessee, 22-24 June 1988. This workshop was sponsored by, and intended to benefit, the Department of Energy (DoE) sponsored PDI program operated in the Nuclear Weapons Complex (NWC). Participating companies and government organizations included all the national laboratories such as Lawrence Livermore, Sandia, and Los Alamos, and their respective manufacturers such as Allied-Signal-Kansas City, and Martin Marietta-Oak Ridge. Invited speakers represented PDES management and government projects such as GMAP, Integrated Design Support System (IDS), the Navy Rapid Acquisition of Manufactured Parts (RAMP), the NBS' Advanced Manufacturing Research Facility (AMRF), PDES Inc., and Computer Aided Manufacturing-International (CAM-I).

  The PDI is developing PDD and exchange mechanism for use within the NWC to communicate designs from the national laboratories to the manufacturers. The results are to be made available to the PDES organization after

they are tested and validated. The areas in development include geometry, form features, tolerances, numerical controls (N/C), inspection, and PSCM. These areas are being investigated and modeled independently from the PDES work.

- In May 1988, GMAP personnel attended a meeting with Mr. P. Motz of Cincinnati-Milacron, who represented the Intelligent Machining Workstation (IMW), to review the current requirements of the IMW contract for GMAP models. The model of interest for a phase 1 demonstration of the IMW was reviewed and their PDD modeling strategy was detailed. Mr. K. Perlotto then created the detailed PDD model specification for the IMW part for subsequent review. This specification contained instances of all the entities required to create the model, included all attribute data values, and could be used as an input guide to the modeler. The GMAP PDD working form model of the sample test bracket was then created for the IMW program and delivered after converting it to a GMAP exchange file using the System Translator.

- On 26 May, representatives from the United States DoT Transportation System Center, located in Cambridge, Massachusetts, visited Pratt & Whitney to learn about the technical accomplishments in GMAP. This office, formerly part of NASA, was supporting DoD CALS work.

- A Pratt & Whitney GMAP representative attended the Machining Initiatives Aerospace Subcontractors (MIAS) Industry Review Board meeting held 11-12 May 1988 in Cincinnati, Ohio, to determine if the Small Manufactures Improvement Services (SMIS) could be a viable avenue for GMAP technology transfer work. Based on initial findings at the meeting, it appeared that SMIS might be a viable avenue for GMAP technology transfer.

- On 8 June 1988, representatives from Grumman Data Systems, a division of the Grumman corporation, met with members of the GMAP technical team for purposes of technology transfer. Systems analysts from Grumman working on the Rapid Acquisition of Manufactured Parts (RAMP) program explained the requirement to drive RAMP with digital data or PDES, if available. They were interested in exploring the concepts of GMAP and how they might be utilized in their work.

  The Grumman representatives were very interested in the software that would be available to them at the end of the GMAP. They expressed interest in using the GMAP PDD Editor to build PDD models. The capabilities, flexibility, and limitations of the PDD Editor were discussed.

- On 31 October 1988, Ms. Diane Emmerson from Pratt & Whitney, presented a GMAP related paper entitled, "Product Definition Data: Implementation Issues," at AUTOFACT'88, in a technical session devoted to PDD. The paper focused on issues that surfaced during the implementation phase of GMAP and the insight that was necessary to put this technology into production. It presented an overview of the GMAP objectives and accomplishments. It also

described PDD and how it was used in the product life cycle. The paper then described how the GMAP/PDDI system software components were used to enable active file exchange in a heterogeneous computer environment, and how PDD was verified in GMAP.

Other presentations in the session included a PDES update by Mr. Brad Smith, of the NIST, and the use of PDES in the NAVY RAMP program and in the DOE. The session was chaired by Mr. Anthony Skomra of Automation Technology Products (ATP).

- GMAP was included as part of a Pratt & Whitney display at the IMIP conference held in Atlanta, Georgia in December 1988. This display provided an overview of the GMAP contract work and focused on the GMAP interface to the RFC system.

- GMAP personnel held a separate debriefing on 17 February 1989 that focused on how the Air Force Logistic Centers could benefit from the GMAP results. The GMAP team provided insight into what GMAP concepts could be applied at the ALC today, and how the PDES could be used in the future. Presentations were also made by Pratt & Whitney and McDonnell Aircraft Company (MCAIR) personnel on how they will be applying GMAP within their respective companies.

  The debriefing objective was to report on the GMAP contract and to gain logistics centers' support for the use of digital data. It was noted that the logistics centers have evolved from using paper to using film. The next step is the evolution to using digital data. The message of this debriefing is, "a lot of good work was performed under the GMAP program. Here is what use of digital data can do for the logistics center in the future."

- Plans were developed for an end-of-contract Industry Debriefing. The debriefing was scheduled for late May 1989, in the NIST area of Gaithersburg, Maryland. This Debriefing was to be the major avenue to disseminate the salient results of the GMAP program to appropriate representatives of industry and Government. However, it was decided to consolidate this Debriefing with CIM Industry Days to reach a broader segment of interested parties.

- Plans were developed for participation in CIM Industry Days. This conference is scheduled for 24-27 July 1989 in Williamsburg, Virginia. CIM Industry days is hosted by the Air Force and will bring together leaders from Government, industry, and academia to exchange views and information on various issues relating to manufacturing technology. The theme of the conference is "Integrated Manufacturing: More than Just Technology".

  Our presentations will include an overview and key findings of GMAP as well as a display booth. We will staff the booth with Pratt & Whitney personnel who were actively involved in GMAP. We also will make use of GMAP videotapes within the exhibit. Literature will be available describing the GMAP program, program deliverables, and lessons learned.

- In response to a request from the National Computer Graphics Association (NCGA), Ms. Linda Phillips and Ms. Diane K. Emmerson prepared a paper entitled, "GMAP: A Prototype in Active File Exchange," for presentation at the NCGA '89 conference and exposition. The conference, sponsored by NCGA, will be held at the Philadelphia Civic Center 17-20 April 1989. The paper discusses different architectures for file exchange, as well as the GMAP software architecture. It further explains how the GMAP software enables active file exchange and discusses the advantages and lessons learned using this architecture. The paper has been approved for public dissemination by the Air Force.

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APPPENDIX C

TECHNICAL ISSUES IN PRODUCT DATA TRANSFER

Several technical issues in implementing electronic product data exchange in both military and commercial applications exist today. These issues need to be addressed in a cooperative industry setting involving the system suppliers, the users, as well as customers of users. These issues, summarized on the attached graphic, are in four areas:

1. there is a fundamental technology shortfall which requires research and development;

2. product data exchange capabilities are in a highly dynamic and evolving environment which makes implementation and standards extremely difficult to manage;

3. *product data exchange needs to be addressed in light of the entire life cycle,* intorducing integration challenges;

4. special DoD requirements compound the general industry requiremnents.

Technology Shortfalls

- Lack of full product description databases — The database structures to represent and manage product data have not been totally defined. The database software to manage these structures are still in prototype mode. Product Definition Data Interface (PDDI)/GMAP is representative of this capability. The electronic versions of engineering drawings do not include all the data necessary for all the applications throughout product life cycle operations to be able to automatically use that original drawing.

- Lack of a full product modeler — The solids modelers that exist today do not allow a user to enter everything necessary to generate full product description databases. Today's modelers are good at creating geometry and topology, but fail to provide computer sensible information such as tolerancing, features, and notes. Input to the database is currently a significant technology barrier.

- Shortfalls in applications ready to use PDD — Since there is a lack of full product description databases, there are very few existing applications capable of using such a database.

- Lack of configuration control capability — There is a need for better traceability of product design releases. Current product designs, as well as designs of mature products, and their revisions must be retrievable and accurately associated among operations within an enterprise. There is a great deal of manual verification currently taking place.

- Lack of PDD communications network — Today's communication networks are not designed to handle the massive amount of data present in a

sophisticated computer file containing full product descriptions. Limited or condensed product descriptions are currently transmitted. Magnetic tape systems are not effective for rapid and frequent exchanges.

- System performance/workstation functionality — More advances are needed in workstation speed and power, and compression techniques to store large amounts of data.

- Proprietary database security — In many cases, prime contractors are allowing subcontractors direct access to product descriptions and internally-developed application software. The activity could be increased if effective methods were developed to control who is allowed to access data systems and who is allowed to manipulate accessed data or software.

In addition, product data exchange capabilities are in a highly dynamic and evolving environment which makes implementation and standards extremely difficult to manage. The issues that illustrate this problem are:

- Numerous levels of implementation — The current standards, such as IGES, are not implemented to the same extent by CAD/CAM system developers. Data conversion from one system to another can thus become very time consuming and error prone. Also, companies differ in the degree to which they commit to this technology.

- Technology in rapid state of change — Today, state-of-the-art systems can become obsolete quickly. For this reason, some companies wait for the system that is the 'best' system for them. Others are continually experimenting with new capabilities.

- Overlapping technologies — Currently, companies are installing systems such as optical disk systems to automate the storage, retrieval, and archiving of drawings. These systems require communication networks, specialized terminals, computers, and so on. In parallel to this, companies are also attempting to integrate their CAD/CAM systems for the use and manipulation of intelligent drawings. Again, these systems require communication networks, specialized terminals, computers, and so on. In most cases, only a small percentage of the hardware/software environment is common to both implementations. This creates problems in financial justification, training, establishing operational procedures, and so on.

- Dual manual/computerized environment — Manual systems do not change to a totally computerized system overnight. Companies have to keep both systems going while they are transitioning and pay an operational cost penalty in the transition.

- Standards for a rapidly evolving technology — The IGES/PDES efforts are attempting to standardize a technology that is not yet developed. The PDES effort is more of a R&D activity than a standardization effort.

- Education/training gap — Employees throughout an enterprise must be trained not only how to use product data generation, manipulation, and transfer equipment but also how to use it efficiently and effectively. Employees must learn that failure to look at the overall control requirements of the system may result in problems later in the product life cycle. Employees in the life cycle range from those with great expertise in using computers to those with no computer based knowledge.

Integrated Approach

Other issues deal with the need of product data exchange to be addressed in light of the entire life cycle, introducing integration challenges.

- Heterogeneous computing environment — Users are not all going to acquire one single system. There is not one single solution to all product data transfer problems. Different computer systems will prevail among companies and the challenge becomes one of integrating these systems, hopefully, to the degree that it becomes transparent to the user.

- Nonstandard representations of data — There are various ways of creating a specific geometric feature, such as a spline, among system developers. As a result, product data transfers is sometimes impossible, other times the accuracy is uncertain.

- Turnkey systems not adaptable — Many available systems do not meet the specific needs of many companies with unique product lines. Also, they are not easily adaptable to meet the company's unique needs or the company is not large enough to employee the resources necessary to modify such a system. On the other hand, many companies that acquire such systems and modify them to fit their unique needs discover that their system is no longer compatible with others of the same manufacture.

- Full life cycle coverage — Single product databases that can be used by the many islands of automation in the life cycle of a product do not exist. Numerous translators are required to provide product data transfer effectively among the many life cycle operations. Translations are considered deficient for many applications.

- Interface to application software — Existing application software can generally use the databases that are now available. However, as we move toward the use of full product description databases, we will be required to develop new interfaces to these existing applications. But, we will also have the opportunity to automate life cycle applications that previously needed a more complete database.

- Feedback to design — Existing iterative design cycles do not always provide the designer with the information required for accurate decision-making early in the design process. Advances in product data transfer technology will provide more opportunities for effective feedback of information to the design process.